COLLABORATION PATTERNS AND PATENTING IN NANOTECHNOLOGY: EXPLORING GENDER DISTINCTIONS

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COLLABORATION PATTERNS AND PATENTING IN NANOTECHNOLOGY: EXPLORING GENDER DISTINCTIONS

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LIST OF ABBREVIATIONS

AUTM	Association of University Technology Manager
EAS	Earth and Atmospheric Sciences
EPO	European Patent Office
EU	The European Union
GDP	Gross Domestic Product
INPADOC	The EPO's raw data resources
ISI	Fraunhofer Institute for System and Innovation Research
JPO	Japanese Patent Office
NIH	National Institute of Health
NNI	National Nanotechnology Initiative
NSF	The U.S. National Science Foundation
NSTC	National Science and Technology Council
OECD	Organization for Economic Co-operation and Development
PATSTAT	EPO Worldwide Patent Statistics Database
PCAST	President's Council of Advisors on Science and Technology
R&D	Research and Development
SAB	Scientific Advisory Board
S.D.	Standard Deviation
S&T	Science and Technology
S&E	Science and Engineering
STEM	Science, Technology, Engineering, and Mathematics
TTO	Technology Transfer Office
USPTO	United States Patent and Trademark Office
UK	The United Kingdom
VC	Venture Capital
WIPO	World Intellectual Property Office

SUMMARY

Drawing upon the research on gender in science (especially gender and publication and patent productivity), social network studies, and social studies of interdisciplinary research and nanotechnology, this dissertation develops and tests a series of hypotheses to advance the understanding of the gender difference in patenting in the U.S. Ridgeway's theory of gender frame (Ridgeway, 2009, 2007; Ridgeway & England, 2004) is very powerful in explaining gender inequity at both micro- and macro-levels, and thus constitutes the foundation of this study. After laying out the theoretical foundation, I set out to focus on collaboration as one of critical mechanisms accounting for the gender difference in patenting.

While social network scholars maintain that social capital resides in network structure and claim different structures provide different benefits (Borgatti, Jones, & Everett, 1998), I conceive of *diversity* as the most important structural feature of collaboration networks to predict patenting performance, and accordingly develop the concept *boundary-spanning collaboration* to refer to collaboration networks containing relationships to diverse others. Then, I rely on social studies of gender, network, and desired outcomes as well as research on interdisciplinary fields in general and nanotechnology in particular to propose several hypotheses regarding how gender would differ on *boundary-spanning collaboration* and how the differences matter the gender gap in patenting in the context of nanotechnology.

Two sets of analyses, performed on large-scale patent data and individual-level survey data, generate novel and important findings. These results enhance our understanding of the distinct context of nanotechnology, especially with regard to collaboration and gender representation, and the interrelationships of gender, boundary-spanning collaboration, and patenting involvement in this context. In brief, there are three major findings. First, while nanotechnology and patenting activities present new areas for gender studies in science, the influential gender stereotypes always predict the detection of a gender gap. Second, collaboration networks, especially those featured with *diversity*, are relevant to the gender gap in patenting nanotechnology in a complicated way, but the operationalization of *diversity* is the key to comprehend the complexity. Third, the returns from collaborative relationships are generally gendered, but the gender gap in returns varies upon the context where a relationship takes place. Relating these findings to previous research, I highlight the theoretical and methodological contributions of this study, point out its limitations for future research development, and draw pertinent policy implications.

1. INTRODUCTION

Gender matters in science[1]. Both female doctoral degree recipients in science and engineering (S&E) and female professionals in scientific workplace have increased steadily in recent decades (NSF Division of Science Resources Statistics, 2008), but research has continuously found that female scientists' productivity, rank, recognition, and salary are all lower than their male counterparts' (National Academy of Sciences, National Academy of Engineering, & Medicine, 2007). The pervasive gender inequality in professional attainments in science is detrimental to social values and economic development by reinforcing negative stereotypes and discouraging talented people from participating in and contributing to science (Fox, 2008; Hanson, 1996). It is estimated by Hunt et al. (2012) that closing the gap between female and male science and engineering (S&E) degree holders would increase Gross Domestic Product (GDP) per capita by 2.7 percent in the U.S. In addition, exclusion of women as researchers and innovators means not simply loss of talents but the exclusion of the specific types of knowledge women develop and maintain (Kugele, 2010; Schiebinger, 2008). Therefore, the gender gap in science is deemed an ongoing focus of scholarly research and policy debates.

Research productivity, because of its central role in the success of a scientific career, has attracted the most attention (Fox, 1999, 2001; Fox & Stephan, 2001). While

[1] Here science is a broad conception encompassing what could be strictly distinguished as science, technology, and innovation.

vast previous research on gender and productivity focused on publication records and documented a pattern favoring male scientists in publishing (Astin, 1969; Cole & Cole, 1973; Cole & Zuckerman, 1984; Creamer, 1998; Fox, 2005; Fox & Faver, 1985; S. Levin & Stephan, 1998; Long, 1987, 1992, 2001; Zuckerman, 1987, 2001), concerns have been increasingly cast on another indication of research productivity, *academic entrepreneurship*[2] or academic research targeting commercial returns through patents, licenses, and products (Colyvas, Snellman, & Bercovitz, 2012; Ding, Murray, & Stuart, 2006; Meyer & Bhattacharya, 2004; Whittington & Smith-Doerr, 2005).

With a growing emphasis on the direct contribution of universities to economic development, the propensity towards commercializing academic research has expended dramatically among university scientists (Owen-Smith & Powell, 2001; Slaughter & Rhoades, 1996, 2004; Thursby & Thursby, 2002), especially in life sciences (Azoulay, Ding, & Stuart, 2007; Owen-Smith & Powell, 2003). Because of their social relevance, innovation participants have been connected to social power and authority and then the opportunities of being involved in research agenda setting and evaluation (Ruiz Ben, 2012). In addition, commercial outcomes have been gradually considered important for academic scientists' occupational success and rewards, especially in emerging interdisciplinary fields (Jacobs & Frickel, 2009). While commercial involvement is assumed to closely related to established status and a high level of publication productivity (Stuart & Ding, 2006; Zucker & Darby, 1996), scholars worry that the

[2] Some scholars use this concept to refer only to firm founding (e.g. Ding and Choi 2011), but I adopted a broader definition that refers to various commercial activities including patenting, consulting, research collaboration with industry, and firm formation (Franzoni and Lissoni 2009).

change towards commercialization would reinforce the gender inequality in the profession of science because women are generally less successful on these aspects (Ding, et al., 2006; Haeussler & Colyvas, 2011; Murray & Graham, 2007; Whittington & Smith-Doerr, 2005, 2008).

Correspondingly, scholars have set out to examine women's status in various forms of academic entrepreneurship, from disclosure (Duque et al., 2005), licensing (Thursby and Thursby 2005), serving in a firm's scientific advisory board (SAB) (Stephan & El-Ganainy, 2007) and patenting (e.g., Frietsch, Haller, Vrohlings, & Grupp, 2009; Meng & Shapira, 2010; Whittington & Smith-Doerr, 2005), to firm founding (Ding 2004). These efforts have resulted in a consistent finding of a gender gap to women's disadvantage. In the burgeoning body of research, for conceptual and practical advantages associated with patenting activities, more systematic investigations have been undertaken on this particular type of entrepreneurial venture.

There are several conceptual advantages of studying patenting. First, patents share many characteristics with publications (e.g. both have to g through an external evaluation system and the successful ones can help generate qualitative and quantitative indicators for performance assessment (Meyer & Bhattacharya, 2004)), suggesting the considerable knowledge accumulated regarding gender and publication productivity can be used to guide the research of the gender inequality in the new context. In addition, patenting activities do represent entrepreneurial efforts. Patenting related indicators not only have been widely recognized as important for the assessment of national, industrial, and organizational innovative performance (Edquist, 2005; Godfroy-Genin, 2009; Nelson & Rosenberg, 1993), but increasingly considered as a crucial indication of individual academicians' entrepreneurial engagement despite the relatively "light" requirements of patenting for financial and time investment (Jacobs & Frickel, 2009). Also, patenting constitutes one of a few milestones in the commercialization process of academic research (Azoulay, Ding, & Stuart, 2009; Colyvas, et al., 2012), is strongly motivated by commercialization (D'Este & Perkmann, 2011), highly likely to shift academic scientists' research to questions of commercial interest (Azoulay, et al., 2009), and a robust factor leading to the decision of participation in more aggressive entrepreneurial activities such as founding a firm (Stuart and Ding 2006). Therefore, studying the gender pattern in patenting is expected to shed lights on how the general change towards commercialization might affect the gender stratification in academic science.

In practice, the patenting process that requires the public disclosure of inventions suggests methodological advantages. Patents are registered intellectual property rights of codified knowledge of scientific and technological inventions (Kugele, 2010; Troy & Werle, 2008). Publicly available and easily accessible, patent data present a rich and valuable source for various commercialization-related studies (Jaffe & Trajtenberg, 2002). More specifically, patent records, archiving detailed information of filing and granting procedure, technical features and applications, and corresponding inventors over time, allow for various research strategies, qualitative or quantitative, longitudinal or cross-sectional, within a specific technology/industry or across board. Regardless of several shortcomings embedded in patent-derived indicators (Archibugi, 1992; OECD, 2004), the reliability, objectivity, and relevance of these indicators for the study of innovation and commercialization are widely accepted (Narin, 1994; Nesta & Patel, 2004).

A systematic review of the extant research on gender and patenting reveals three major limitations. First, a fundamental understanding has not been established to guide the identification of critical factors and the assessment of their explanatory power for this gap. Second, there is insufficient attention to collaboration, a process generally assumed to promote research productivity (Gale Group, 2008) and be responsible for women's lower productivity (Kyvik & Teigen, 1996). A third issue is the lack of efforts in focusing on nanotechnology as a field context to study the gender pattern in patenting, and a relevant implication of this gap is the under-developed knowledge about the gender pattern in both patenting and nanotechnology.

Motivated by the new research agenda and attempting to address above limitations, this dissertation investigates the gender pattern in patenting with a focus on collaboration mechanisms and the context of nanotechnology. Drawing insights from the social studies of science and social network research, it first conceptually identifies the most important feature of collaboration networks in relation to patenting. And from there, hypotheses are developed concerning the potential role of collaboration networks with such a feature in differentiating women's and men's patenting in nanotechnology. Finally, these hypotheses are tested with the use of empirical data. Throughout the research, the main research questions guiding my literature search and theoretical framework building include **how and why collaboration mediates the gender effects on patenting and how and why the process would be different in nanotechnology.**

This study is expected to extend the research on gender and patenting, nanotechnology, and the professional of science, in a few ways. First, it devotes special attention to the social mechanism of collaboration, theoretically and empirically exploring its relationship to the gender pattern in patenting. In this sense, it also extends the research on gender and collaboration as well as collaboration and patenting (and other commercial activities). Second, it captures the emergence of nanotechnology in the scope of science, trying to understand whether and why it provides a distinct context for female scientists and their patenting activities relative to their male colleagues. Lastly but most importantly, by explaining the gender gap in the intersection of the two new areas, patenting and nanotechnology, the study unfolds the fundamental cause for the prevailing gender differences at each corner of science.

The research also contains methodological novelties. In addition to use individual-level data to testify the hypotheses, patent analysis based on large-scale[3] patent data is adopted to reveal several gender- and collaboration-related patterns in nanotechnology. The multi-methodological approach provides a more complete picture about the relationship of gender, collaboration, patenting, and nanotechnology. Given that identification of inventors' gender[4] is essentially important to the patent data analysis, one specific contribution of this study is the extension of the first name database to include names of Asian origins and its application for the identification purpose. Practically, the updated knowledge base should help generate policy implications for improving women's status in science.

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[3] This refers to the scale of the patent data (usually hundreds of thousands patent records) that is comparatively larger than the scale of survey or interview data.

[4] Being aware of the difference between gender and sex, with the former referring to the social construction of men and women and of masculinity and femininity and the latter to biologically determined characteristics (European Commission 2009), I decided to use gender consistently in the whole study.

The dissertation is organized as follows. In Chapter 2, after reviewing Ridgeway's theory of gender frame and placing it as the foundation, it systematic reviews the literature along three lines – patenting, collaboration, and nanotechnology, based on which it generates hypotheses on how collaboration could explain the gendered patenting in the new context of nanotechnology, and build a conceptual framework incorporating the hypothesized relationships. Chapter 3 describes the data sources, including those providing the patent data and the data of individual academic scientists, as well as the manipulation of these data for the current research purpose. It also defines key indicators and variables and discusses the analytic methods for this study. Chapter 4 reports and interprets the findings from two sets of analyses – patent data analyses and the analyses of individual-level survey data. Chapter 5 concludes with a summary of major findings in relation to previous research, and a discussion of limitations, directions for future research, and policy implications.

2. LITERATURE REVIEW

The dissertation research is situated in the broad sociological work of science and technology, and social capital and social network research (especially with regard to women in professional workforce). In this chapter I start with a systematic review of the transition of research focus in the literature of gender in academic science, particularly from studying the gender difference in publication productivity to the gender pattern in patenting, an important form of academic entrepreneurship. After pointing out major limitations in the extant research on gender and patenting, I review important research on collaboration and research productivity and explore the concept of collaboration and its association with patenting from a relational perspective rooted in social capital theory. Finally social studies of nanotechnology and interdisciplinary research are reviewed to draw implications on how women may differ from men in collaboration and patenting in the context of nanotechnology. Based on hypothesized relationships developed from the literature review, I present an integrative conceptual framework for further empirical examinations.

2.1. Patenting: A New Arena for Research on Gender and Scientific Productivity

2.1.1. Traditional Studies of Gender and Scientific Productivity

For decades, academia and industry have operated as distinct institutions that hold fairly different logics and mechanisms for knowledge creation and dissemination (Cohen, Nelson, & Walsh, 2000; Hong & Walsh, 2009; S. Levin et al., 1987; J. Singh, 2005). As the reward system in the academy emphasizes the priority of discovery and the contribution to the common stock of knowledge, academic scientists struggle to earn their reputation and recognition primarily through publishing their new findings. The norms and reward system speak to the central role of publication in a successful career in academic science. Then scholars concerned with the gender inequality in scientific careers have devoted tremendous attention and efforts to the gender difference in publication productivity.

As early as forty years ago, scholars already reported the general lower level of women's publication productivity and, since then, the gender difference has been well documented as a consistent pattern over time and across disciplines and cultures. This volume of research can be traced back to the point when Cole (1979) reported, in chemistry, biology, psychology, and sociology, men had published more than two and half times as many papers as women. In their review of about fifty empirical studies, Cole and Zuckerman (1984) concluded that women scientists published just over half of the number of peer-reviewed papers that men did. Long (1992) found, while only a small difference was discerned between women and men biochemists at their receipt of Ph.D., the difference jumped to a substantial level in their third or fourth career year (66 percent up from 26 percent more average articles per year). The gap remains noticeable although some evidence indicates it is narrower among scientists in recent Ph.D. cohorts and in a few fields. For example, analyzing the data from four large-scale, nationally representative, and cross-sectional surveys of postsecondary faculty, Xie and Shauman (1998) reported the female-to-male publication ratio reached about 80 percent in the early 1990s, up from around 60 percent in the late 1960s. Sonnert and Holton (1995a) found a significant gender difference on their publication measure, with men on average having 2.8 publications and women 2.3 annually, but the difference is relatively small in the field of biology.

To the extent the distribution of publication among scientists is highly skewed (Fox, 1983; Lotka, 1926; Price, 1963), the finding that the highly productive scientists are predominantly male (or nonpublishers are predominantly female) is another indication of the gender difference. In the study mentioned before, Long (1992) further uncovered that the lower productivity of women could be attributed to a greater proportion of nonpublishers in this group; among those who published, the annual publication counts did not vary significantly between men and women. In a study of scientists who were recipients of prestigious NSF and NIH postdoctoral fellowships, women only accounted for 13.9 percent of the highly productive group of scientists who published 5.5 articles or more per year, and at the same time women were twice as likely as men to be less productive (Sonnert & Holton, 1995a). All these refer to women's disadvantages in publishing, at least in the quantitative term.

By the mid-1980s, as the gender difference on publication rates was not eliminated after different factors were accounted for, Cole and Zuckerman (1984) referred to it as "productivity puzzle." Vast efforts have been invested in resolving the puzzle thereafter. One prevailing argument is the operation of particularism or discrimination. However, simple measures of outcomes between groups, whether different or similar, are not evidence of discrimination because similar outcomes may result from particularistic processes and different outcomes may result from universalistic processes (Long & Fox, 1995). Then a general strategy has become to examine whether there is residual on gender after controlling for relevant factors (Cole, 1979; Long & Fox, 1995). While this approach depends critically on the appropriate specification of variables to be controlled, two classes of variables – individual-level and structural-level variables – are generally identified and examined. It was claimed recently that "most of the observed sex differences in research productivity can be attributed to sex differences in personal characteristics, structural position and marital status"(Xie & Shauman, 1998), but as the authors stated, new puzzles are raised regarding gender differences on the important personal dimensions and structural processes. It has to be noted, while individual variables (including demographic characteristics and education background) may explain part of women's disadvantages, they do not exist in a vacuum but are instead shaped by social and structural factors (Fox, 1991), and therefore social and structural variables are more critical to explain the differences between genders. Therefore, we should go back and understand how gender shapes various social processes in a fundamental way.

Gender is one of two or three primary frames in our society that guide the organization of social practices (Ridgeway, 1997, 2007). According to Ridgeway, as people depend on others to attain most of what they want and need in life, they have to develop "common" knowledge as a basis for interaction and coordination. Common knowledge then becomes cultural knowledge that we assume everybody knows and also based on which we can anticipate each other's actions and react accordingly. How to categorize self and other is a piece of common knowledge that is useful to define the situation and make sense of one another in social practices. In the meanwhile, such a category system should be simplified to allow for real-time management of actions.

Consequently, as social cognition studies revealed, only a very few cultural categories provide the primary guidance for individual perception and action in relation to others, and gender is in the short list (Brewer & Liu, 1989; Ridgeway, 2009, 2006, 2007).

As gender is used as a primary cultural frame for differentiation and categorization, “difference is easily transformed into inequality through any of a variety of social processes” despite “difference need not logically imply inequality” (Ridgeway 2009: p149). In the core of these various social processes is the sustainability of the mutual dependence of groups, and to this end, consensus has to be built among members from different groups on which one is more respected and status-worthy than others (Ridgeway 2006). In reality, as research found the existence of consensual gender beliefs (i.e. held by both men and women), it also found that these beliefs view men as more proactive and competent in general and more competent at the things that “count most” in society; and view women as less competent generally but better at more feminine, communal tasks that tend to be socially less valued (see Ridgeway 2006 for a comprehensive review). Science connects with power (Fox 2001) and thus is socially privileged and imprinted as a masculine area. This explains why women are generally treated in science as “stranger” (Sonnert & Holton, 1995a), “outsider” (Zuckerman, Cole, & Bruer, 1991), “token” (Kanter, 1977a, 1977b) and illegitimate group members (Burt, 1998). While the production of scientific knowledge is a complex process involving many interactive activities between female and male scientists, the beliefs (or more precisely *stereotypes*) work behind various interactions. While their actual effects may be subject to specific contexts, it is hard to eliminate these stereotypes (Ridgeway 2009). Considering together, it is not surprising that women are disadvantaged in the key processes related to publication productivity and ultimately disadvantaged on publication productivity (especially on quantitative measures that dominate the current evaluation system). However, what deserves more attention and efforts is how the gender stereotypes interact with contextual factors to have varying effects on productivity-related social processes and consequently the gendered productivity. This study hopes, by unrevealing the potentially differential gender distinctions in collaboration and patenting in nanotechnology, to provide empirical support for Ridgeway's (2009) theory.

2.1.2. The Changing Environment and the Rise of Academic Patenting

In recent years, the world of academic science has undergone a significant change towards application and commercialization. This is mainly driven by a remarkable shift of national S&T policy with a new emphasis on involving universities and public research agencies more directly in economic development (Etzkowitz, 2008; Slaughter & Rhoades, 2004). In the late 20th century, innovation concepts fascinated policy scholars as well as policymakers. The pass of Bayh-Dole Act (that legitimates the intellectual property control of universities, small-businesses and non-profits over their inventions resulted from federal government funded research) and a series of policies around innovation concepts such as "innovation systems" ((Edquist, 1997; Freeman, 1987; Lundvall, 1992; Nelson & Rosenberg, 1993) and "triple helix" (Etzkowitz, 1993, 1998, 2008; Etzkowitz, Webster, Gebhardt, & Terra, 2000) has encouraged individual researchers to patent, universities to institutionalize technology transfer offices (TTOs), and private funding to flow into university research (Whittington, 2007). Gradually, the boundary between academia and industry blurs (Hong & Walsh, 2009; Powell & Owen-Smith, 1998; Slaughter & Leslie, 1997; Slaughter & Rhoades, 1996; Whittington, Forthcoming; Whittington & Smith-Doerr, 2005), and academic scientists have more opportunities to engage in various entrepreneurial activities (Mowery, 2007; Thursby & Thursby, 2002 among numerous others).

Some evidence about academic entrepreneurship seemingly shows that universities and faculty scientists tend to embrace the new regime. For instance, while the number of patents issued to inventors doubled in the early 2000s compared to the number in the mid-1980s, the stock of academic patents increased nearly eight times in the same period in the U.S. (Powell, White, Koput, & Owen-Smith, 2005). Another study claimed that the number of U.S. patents filed through universities witnessed 16-fold increase from 1980 to 2004 (Sterckx, 2011). While patents awarded to universities only accounted for 0.5 percent of all U.S. origin patent grants in 1980s, the proportion reached about 5 percent by late 20th century (National Science Board, 2000). Besides the impressive increase of TTOs in universities (from around 30 before 1980 to 300 nowadays), universities (such as Texas A&M University) start to include patenting in tenure and promotion evaluation (Parker & Evans, 2006; Whittington & Smith-Doerr, 2005). Studies also documented scientists' attitudinal shifts from opposition to acquiescence to acceptance (Colyvas & Powell, 2007; Etzkowitz, 1989, 1994, 1998, 2001).

However, concerns from both policymakers and individual scientists arise regarding the impacts of the changing culture and practices. Research on academic scientists' entrepreneurial activities has quickly grown as a response to these concerns (e.g. Bok, 1982; Frickel & Moore, 2006; Nelson, 2004; Slaughter & Leslie, 1997). One small but quickly growing stream, with a focus on patenting, attempts to answer whether and how the change affects the gender stratification in science, which is summarized in the following sub-section.

2.1.3. Extant Research on Gender and Patenting

Research on gender and inventive and intellectual property right pursuing activities is not completely new, but earlier studies tended to provide anecdotal or historical accounts of women inventors and their inventions (Khan, 1996, 2000; Macdonald, 1992; Pursell, 1981; Stanley, 1993; Vare, 1988). Only until recent few years have empirical and systematic investigations of the gender pattern of patenting emerged (see the following paragraphs for a detailed review), coupling with the dramatic increase of academic entrepreneurship. While two distinct approaches have been adopted in the growing volume of research on this theme, the results generally point to a gender gap in patenting to women's disadvantage.

One major source of information about inventors is surely patent documents stored in different national or international patent offices. By way of matching first and middle inventor names against a list of known female names to identify female inventor as well as their patents, the U.S. Patent and Trademark Office (USPTO) reported the share of U.S. origin patents[5] in all categories that include at least one woman inventor increased from 3.7 percent (in the period 1977-1988) to 9.2 percent in 1996 and then 10.9 percent in 2002 (Rosser, 2009; USPTO, 2003). Regardless of some progress, the percentage of patents obtained by women is even lower than the percentage of female doctorates in science, technology, engineering, and mathematics (STEM) and female

[5] The origin is determined by the residence of the first-named inventor.

employees in the STEM workforce, suggesting women's limited role in patenting in general (Ejermo & Jung, 2012; Kugele, 2010; Rosser, 2009). A study conducted by Ashcraft and Breitzman (2007) from the National Center for Women and Information Technology revealed that only about 9 percent of U.S. origin patents in information technology (IT) included at least one female inventor, and the proportion further dropped to 4.7 percent when using fractional counts. In an initial effort to explore the gender difference in patenting nanotechnology, Meng and Shapira (2010) examined the U.S. domestic patents[6] in a Global Nano-Patent Database (detailed information about this database is offered in Chapter 3) and found that the ratio of female to male inventor observations to be 1:9 (after excluding those whose gender was unable to be identified) and around 17 percent of patents published during 2002-06 in nanotechnology had at least one female inventor. Studies using the patent records from different sources to probe the gender pattern in patenting did find women's lower rates of patenting in Japan (Ashcraft & Breitzman, 2007), the European Union (EU) (Kugele 2010), and specific European countries (Ejermo & Jung, 2012; Frietsch, et al., 2009; Mauleón & Bordons, 2009, 2010; Naldi, Luzi, Valente, & Parenti, 2004; Naldi & Parenti, 2002).

Studies relied merely on patent records, however, have their limitations. First, patents do not list all individuals involved in invention and innovation. Inventors may choose alternative methods (e.g. secrecy or direct licensing) instead of patenting for strategic protection and commercialization (Levin et al. 1987; Griliches 1990). Second, patent documents do not record detailed information about inventors' demographic

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[6] If a patent has one listed inventor residing in the U.S., it is coded as a U.S. domestic patent.

background, career history, network features, and employer's characteristics, which prevents a more comprehensive understanding derived from more sophisticated and explanation-oriented analyses. As an alternative approach, analysis of survey data (usually with a focus on academic scientists) has been used in other research in this literature.

By analyzing the survey data through the NSF's Scientists and Engineers Statistical Data System (SESTAT), Morgan and peers (2001) found that in education sector (including researchers in all types of educational institutions and in nontenure-tracked positions), women comprised 25 percent of the doctorate-holding population but only held 11 percent of the patents filed in this sector; and the pattern with women having a lower rate of patenting was also found in industry. Whittington and Smith-Doerr (2005) found, based on their examination of more than 1,000 life scientists who had received National Institutes of Health (NIH) training grants, that female scientists patented less than male scientists – 12 percent of female and 30 percent of male scientists had ever patented in the whole sample. The difference held true across three generational cohorts (Ph.D. in 70s, 80s, and 90s). But they also reported there was little substantial difference between genders if qualitative measures (generality and originality) were used, that is to say, women's patents were equal to or even better than men's in terms of quality or impact. In their other study using the same database (Whittington & Smith-Doerr, 2008), women were found to be less likely to patent than men in both academia and industry, although the gap is smaller in the latter context.

Performing an analysis on a random sample of life scientists drawn from the UMI Proquest Dissertation database, Ding and colleagues (2006) found a statistically significant gender difference net of the effects of publication productivity, networks, field, and employer attributes, with women patenting at only 40 percent of their equivalent male counterparts. Using a small sample drawn from biotechnology faculty in one top research university, Murray & Graham (2007) identified a salient gender gap: men on average had a higher rate than women in the transition to patenting. And the gap held true over four generations – “distinguished” (pre-1975), “senior” (1976-1985), “mid-career” (1986-1994), and “junior” (1995-research year 2005). McMillan (2009) used a small sample drawn from biotechnology faculty in one top research university to demonstrate that women lagged men scientists in patenting to a substantial degree: among the 1,903 patents that could be identified with inventors’ gender, women filed only 4 percent alone; among over 5,000 inventors whose gender could be classified, only 897 (17%) were female. As Whittington and Smith-Doerr (2005), McMillan also found women’s patents were not significantly different from men’s in terms of generality and originality, but they reported that women also received more citations than men. As most studies along this line are confined in life sciences (or biotechnology), in combination with the findings from research on large-scale patent data, they are suggestive of the universal existence of the gender gap in patenting if only patent counts are used to measure performance in patenting.

Scholars have proposed different explanations for this gender gap. Irrespective of its descriptive nature, the results from analyzing large-scale patent data imply that independent work may be an issue for improving women’s participation and productivity in patenting (Ashcraft & Breitzman, 2007; Mauleón & Bordons, 2009; Meng & Shapira, 2010). Whittington and Smith-Doerr (2008) claimed that organizational structure is a

Table 2-1 A summary of explanations for the gender gap in entrepreneurial activities

Supply side	Demand side
Women are more risk averse Women dislike competition more than men Women are less socialized to "sell" science Women work more in "uninteresting" *niche* areas Women are less productive and less famous Women have more family obligations Women are located in less innovative areas Women are less exposed to commercial activities	Women are excluded from employers' networking Venture capitalists favor men to women Women are less likely to be asked when opportunities are available Women are more likely to have their credentials discounted Men occupied the top status in enterprises The emerging "boys' club" in arena of commercial activities

Source: Stephan and El-Ganainy (2007)

critical variable to account for the gap and argued a networking organizational structure would be conducive to more patenting engagement for women, based on their finding that women are more likely to produce patents in biotechnology firms than in academia or large pharmaceutical companies. Ding and peers (2006) considered, based on anecdotal evidence from their interviews, the lack of exposure to commercial sector and suspicion of the rewards of commercial engagement hinder women's patenting activities.

Murray and Graham (2007) found the gender difference was larger in older cohorts and argued it was the opportunity structure created by supply and demand factors as well as their interactions that placed female scientists in a disadvantaged situation in patenting and other entrepreneurial activities. They recommended mentoring, institutional support, and appointment to high profile administrative positions would work to reduce the gender difference because they found these measures did help narrow the gap in younger generations. Similar to Murray and Graham's argument, Stephan and El-Ganainy (2007) also provided a variety of explanations grouped as demand and supply factors (summarized in Table 2-1) for women's lower level of participation in patenting and other entrepreneurial activities.

No evidence has suggested that women are less capable of patenting their research (Swede, 2003). Indeed, the explanations reviewed above implies that the gap tends to result from a wide variety of social mechanisms and their interactions in S&T where norms and practices are historically constructed as masculine and the gender stereotypes function as a driving force behind these mechanisms (Ridgeway 2009). In brief, a combination of differences in women's and men's professional socialization, networking, efforts in balancing family and work, and their capabilities perceived by critical others serves as the principle contributor to the gap. The fundamental explanation leads us to predict such systematic gender stratification would endure in the foreseeable future (Murray and Graham 2007; Ejermo and Jung 2012). Along this logic, nanotechnology, a new field about which we have little knowledge, would not be immune to the gendered pattern:

H1: Women have a lower level of patenting than men in nanotechnology.

Although the gap is quite certain, as I stated earlier, more research needs to be undertaken to understand how the gender stereotypes, in interacting with dissimilar contexts, would affect the processes and practices crucial to scientific productivity (patenting here) in these contexts and ultimately lead to some change in the gendered patenting. Indeed, some scholars have provided good examples for this sort of changes. For instance, research found even though women produced fewer patents than men in innovative biotech firms, they achieved more supervisory positions (Smith-Doerr 2004) and attain greater parity with men in terms of patenting participation than their counterparts in traditionally hierarchical academia or pharmaceutical companies (Whittington and Smith-Doerr 2008). In Murray and Graham's study (2007), cohorts were suggested to present different contexts and the gender gap in patenting reduced in the recent cohorts in which perceptions and practices were still gender-typed but less salient due to the availability of mentoring and institutional support to women.

Unfortunately, the gender contrast in terms of patenting has rarely been examined in nanotechnology except two preliminary studies (Meng & Shapira, 2010; Ruiz Ben, 2012) and with a focus on the mechanism of collaboration. Given that nanotechnology is supposed to present a distinct context from life sciences and established disciplines regarding women's participation, collaborative behaviors, and performance (Rhoten, 2003; Rhoten & Parker, 2004; Rhoten & Pfirman, 2007), filling this research gap becomes imperative. As for the lack of a perspective from collaboration, research on gender and publication productivity has sent the message that collaboration is critically relevant to research productivity and suggested such a lack is problematic. For the same reason, I did a search in the literature on gender and publication productivity for a specific relationship between collaboration and research productivity. Upon a systematic review of this literature, I recognized its insufficiency and turned to the social network and social capital theory for a deeper understanding of the benefits residing in collaboration. All of the efforts are presented in the following section.

2.2. Collaboration: An Important Structural Variable

2.2.1. Collaboration in Social Studies of Science

2.2.1.1 The Relationship between Collaboration and Publication Productivity

It is generally assumed that collaboration can enhance scientific productivity. As scientific collaboration is established based on joint efforts to achieve common goals, it presents a way for knowledge producers to continuously interact and share skills and resources (Katz & Martin, 1997). Scientific research is fundamentally a social process – ideas are born, developed, and refined through communication and exchange (Fox, 1983) – and arguably collaboration that allows for effective communication and exchange of resources and skills would enhance publication productivity. While collaboration has always been an important aspect of scientific research, scientific collaboration has become more intensive and had a more determining role in scientific productivity, due to increasing complexity of research problems, diversified sources of research funding, quick upgrade of communication technology, further specialization in expertise, and rapid growth of scientists and knowledge (Hara, Solomon, Kim, & Sonnenwald, 2003; Walsh & Maloney, 2002).

Empirical evidence seems supportive of the positive role of collaboration in promoting research productivity. Price and Beaver (1966) found that, even after adjusting for multiple authorship[7], joint-paper authors were still the most productive. Based on an analysis of collaborative patterns in chemistry at both group and individual level, Pravdic

[7] This means that only 1/n of a point is assigned when a scientist's name occurs in an article with n authors.

and Oluic-Vukovic (1986) found the publication counts were closely associated with the frequency of collaboration among authors. Studies also suggested that, across various fields, co-authored papers were more likely to be accepted from an editorial perspective (Gordon, 1980; Lawani, 1986; Presser, 1980; Zuckerman & Merton, 1971). A more recent study (Lee & Bozeman, 2005) indicated the number of collaborators, net of other effects, was a robust predictor of publication productivity. Evidence also suggested that researchers who collaborated, compared with those who work alone, published articles in a higher quality measured by citations, the impact of journals, and the span of time to receive citations (Preston, 2004).

The connection between collaboration and publication productivity, however, ought to be read with caveats. First, some research found that the increase of collaboration had no direct association with publication growth (e.g. Duque, et al., 2005), implying costs should never be overlooked or assumed always to be offset by benefits. Second, the bibliometric approach, while pervasive in this literature, is also questionable, especially when adjudicating whether co-authorship is equivalent to collaboration (Bozeman & Corley, 2004; Fabrizio & DiMinin, 2008; Katz & Martin, 1997). In addition, researchers have recognized the effects of collaboration are contingent on collaborators' background. For instance, Pravdic & Oliuic-Vukovic (1986) found that collaborating with prolific authors was likely to increase individual productivity, and having collaborators with a lower level of productivity might decrease productivity. Taken together, how collaboration affects publication productivity still remains an open question.

2.2.1.2 Gender, Collaboration, and Publication Productivity

Regarding women (as opposed to men) in collaboration, research findings are mixed. On the one side, women seem inclined to collaborate. Reskin (1978b) argued that women scientists are less professionally confident and therefore more dependent on support from their work environments. This point is supported by a study of research groups in the natural science and technology in six European countries (Stolte-Heiskanen, 1983). Stolte-Heiskanen found, while the same number of women and men had frequent contact with their group leader, many more women than men thought this contact was important for their own work. On the other side, women are likely to be excluded from informal communication and collaboration as a minority group. Anecdotal evidence suggested women in male-dominated universities had problems in becoming integrated into important informal networks (Bernard, 1964; Cole, 1979; Fox, 1991; O'Leary & Mitchell, 1990; Reskin, 1978b). And thus their opportunities for collaboration were greatly restricted (Cole, 1981).

The quantitative evidence about women's and men's collaboration is inconsistent too. Using co-authorship as a measure of collaboration, Hunter and Leahey (2008) and Kyvik and Teigen (1996) found a higher percentage of men's than women's articles were single-authored, but Pripic (2002) found the opposition. Long (1990) reported that women and men had an identical level of collaboration as in both groups: 56 percent had at least one article co-authored with their mentors. Using self-reported collaborators as an indication, three studies reported that women tended to have fewer collaborators than men (Cameron, 1978; Cole & Zuckerman, 1984; Corley, 2005) and two found no differences between genders with regard to the number of collaborators (Bozeman &

Corley, 2004; S. Lee & Bozeman, 2005). Based on large nationally representative survey data of academic scientists and engineers, two most recent studies found that female scientists had more collaborators than men (Bozeman & Gaughan, Forthcoming; Welch & Melkers, 2006). While the inconsistent results may be attributed to the use of different samples and different measures of collaboration, questions rise as to which measure should be adopted to truly reflect women's and men's situation in collaboration.

As productivity is further concerned, the evidence is very rare. Although the "exclusion hypothesis" suggests women's lower publication rates is partially due to their isolation, voluntary or involuntary, from interaction and collaboration (Helmreich, Spence, Beane, Lucker, & Matthews, 1980; Reskin, 1978a), this hypothesis has received little empirical examination (except for Kyvik & Teigen, 1996; Long, 1990). In studying the publication productivity (measured with counts of journal articles in a 3-year period ending the year after the Ph.D. was earned) of a sample of doctorate biochemists, Long (1990) found, of those who did not collaborate (having at least one co-authored article) with their mentors, 61 percent of men compared to 75 percent of women did not have publications in the focal three years, and inferred that lacking collaboration with mentors had a negative impact on women's productivity. The issue in Long's work is conceptually ambiguous as collaboration and productivity were both measured through publication counts.

A study of faculty members from four Norwegian universities discovered that women were less likely to collaborate with colleagues (inside or outside of their departments) and the negative effects of lacking collaboration on publication productivity only existed in the female group (Kyvik & Teigen, 1996). But the validity of the findings in Kyvik and Teigen's work is challenged as the sample included faculty members in Norwegian university and fields in humanities and social sciences. In short, the question of whether women differ from men in collaboration and whether such a difference contributes to the gender difference in research productivity requires more investigative efforts.

2.2.2. Social Network, Gender, and Patenting

As individuals are connected by collaborative relationships, they become embedded in an entity (network) that has structural features and poses social influence on them in turn. Therefore, one advantage of the collaboration perspective in explaining individual performance is to consider the structural characteristics of a collaboration network that are suggestive of different social influences on individuals located in the network. This point has been well developed in social network and social capital theory (Marin & Wellman, 2010). In the social studies of science, although not specifically targeting collaboration network, scholars have increasingly examined the relationship between scientists' networks and their performance in creating knowledge and technology (Lee, 2010; McFadyen, Semadeni, & Cannella, 2009; Perry-Smith & Shalley, 2003; Rost, 2011; Jasjit Singh & Fleming, 2010; Walsh & Maloney, 2002). Sharing the same lens, this study explores the core issue of interest involving gender, collaboration, patenting, and nanotechnology from the network perspective. This sub-section briefly introduces the social network theory, identifies the key attributes of collaboration networks in relation to patenting, and presents hypotheses regarding the relationship between collaboration and patenting performance and how that relationship may vary across genders.

2.2.2.1 Social Network Approach

Several classical definitions of social capital (Bourdieu & Wacquant, 1992; Coleman, 1990; Lin, Cook, & Burt, 2001; Putnam, 1995) contain two fundamentally distinct viewpoints. One conceives of social capital as a group-level or societal quality, whereas the other treats it as benefits for individuals from their social networks (Borgatti, et al., 1998; Lin, 1999). Given my current research focus, I only review the research along the second line.

By defining *capital* as "investment of resources with expected returns in the marketplace" (p.3), Lin (2001) differentiated *social capital* from *human capital* (residing in individuals) and *cultural capital* (the acquisition of the dominant culture and its values). According to Lin, *social capital* suggests that "actors (whether individual or corporate) are motivated by instrumental or expressive needs to engage other actors in order to access these other actors' resources for the purpose of gaining better outcomes" (p.xi). Lin (2001) articulated the benefits of being tied with others in terms of information, influence, social credentials, and reinforcement. Specifically, social ties can provide an individual with useful information about opportunities and choices under imperfect market conditions. Social contacts, due to their legitimate status or strategic locations, can impose influential impacts on decision makers and decision-making processes regarding the individual. Those with whom an individual has built relationships may be considered as those "standing behind" the individual to certify his/her credentials. Additionally, as becoming a member of a social group can provide both emotional support and public acknowledgement about one's accessible resources, social relations functionally reinforce identity and recognition.

Because different relationships mean different resources or capital (Ibarra 1993), scholars try to differentiate relationships for the study of social capital. For instance, scholars have distinguished instrumental versus expressive relationships (Ibarra, 1993; Tichy, Tushman, & Fombrun, 1974; van Emmerik, 2006). Instrumental ties are developed around work related roles and involve obtainment, accumulation, and exchange of performance related resources, such as information, expertise, advice, and material resources. Expressive relationships characterized by great closeness and trust function to provide emotional and social support. It is possible that a relationship involves both instrumental and expressive components (Ibarra, 1993) and the expressive component may enhance instrumental outcomes (Kiopa, 2011). But because one focus of the current research is patenting, a professional outcome, and women's networks generally consist of more expressive ties (Hitchcock, Bland, Hekelman, & Blumenthal, 1995; Marsden, 1987; Moore, 1990; Renzulli, Aldrich, & James, 2000; Umberson, Chen, House, Hopkins, & Slaten, 1996), distinguishing instrumental and expressive relationships and focusing on the former is important here.

There are other ways for classification. As Coleman emphasized the solidarity benefits of professional networks, he and his followers (Adler & Kwon, 2002) asserted strong ties are conducive to fast transfer of tacit knowledge (especially complex knowledge). In his work on the strength of weak ties, Granovetter (1973) elaborated the new information benefits associated with "weak ties." McPherson and colleagues (McPherson, Smith-Lovin, & Cook, 2001) developed the concept "homophily" to refer to similarities between an individual and his/her contacts and discussed its advantages and disadvantages. Therefore, the benefits of collaboration may be considered as a variant and there is a need to specify benefits according to specific studied outcomes. Then what kind of collaboration is most relevant to patenting, an outcome of the current interest? I search the answer by relating the challenges facing academic scientists to patent their research with developing certain type of collaboration that may help deal with these challenges as suggested by the network research.

2.2.2.2 Boundary-spanning Collaboration and Patenting Performance

Patenting, regardless of its increasing importance, is by and large an “optional” activity for faculty scientists, and involves costs. To apply for a patent, either through the university TTO, the consulted company, or by themselves (see Appendix A for the general information about the process of patent application and grant), academic scientists have to devote additional time at least to completing the patent document, if not to other responsibilities (e.g. identify a patent lawyer, seek for a potential industrial licensee, manage the licensing process etc.). In addition, as universities traditionally function as a noncommercial environment, faculty scientists are likely to have little knowledge about entrepreneurial process and face challenges in terms of university support (Mowery, 2007). As a result, time has to be reallocated between traditional academic responsibilities and commercial activities. Lack of balance between these two broad categories of activities may negatively affect a faculty researcher’s career development. Also, research found that technologies demanded by the market were more applicable and do not reflect academic research frontier (Thursby, Fuller, & Thursby, 2009; Trajtenberg, Henderson, & Jaffe, 1997), suggesting aggressive commercial endeavors may lower the quality of an academic scientist’s research.

Then collaborating with strategic others may be an efficient way to accumulate broad legitimacy (Delmar & Shane, 2004; Mosey & Wright, 2007), minimizing the costs of patenting and enjoying its benefits. However, who are strategic others? What collaboration networks are featured with containing the strategic others? For these inquiries, we should bear in mind that patenting is not simply a purely knowledge creation activity but more a boundary-spanning activity involving lots of learning, negotiation, and resource motivation in interaction with different institutions. Following the academic entrepreneurship literature and broad research on innovation (Ding 2004; McFadyen et al. 2009; Perry-Smith and Shalley 2003; Burt 2004, among many others), I argue that networking with trustable others who have different background should bring more benefits to academic scientists and promote their patenting performance. In a sum, trust and diversity has been considered the most important aspects of networks for innovative endeavors.

Differing from general networking ties, collaborative relationships are established and developed through joint commitments to some goal and should contain *trust*, an important component that has been well demonstrated to guarantee easier and faster transfer of information and attitudes (Burt, 2000; Higgins & Kram, 2001; Lin, Ensel, & Vaughn, 1981), especially complex ones (Hansen, 1999). Then, *diversity* may be the most influential feature of collaboration networks to affect patenting performance. In his work on the strength of ties, Granovetter (1973) emphasized the information benefits from weak ties, that is, actors can access novel information and ideas through the ties lying outside of their immediate cluster of contacts. Burt (1992) argued the strength of ties is a correlate, but not a determinant, of unique information provided by an individual's network. According to him, it is the contacts disconnected from others in the individual's network that offer benefits. In other words, bridging *structural holds*[8], where ties between actors are absent, would benefit individuals in obtaining additive (instead of redundant) information, more new opportunities for inclusion, and more control power over strategic and scarce resources. The S&T human capital theory (Bozeman, Dietz, & Gaughan, 2001; Dietz & Bozeman, 2005) stresses the benefits of a social network with a broad range in transferring tacit knowledge, underscoring the importance of the diversity feature as well. Heinze and Bauer (2007) found that comparable to their ordinary peers, highly creative scientists in the field of nanotechnology had more access to "richer and more diverse expertise." Ample other studies using different definitions and measures of *diversity* tend to support this point (Ancona & Caldwell, 1992; Ding, et al., 2006; Levin & Cross, 2004; McFadyen, et al., 2009; Reagans & McEvily, 2003; Reagans & Zuckerman, 2001; Rost, 2011).

After *diversity* is identified as the key to engage scientists in patenting, I further narrow my focus on academic scientists' *boundary-spanning collaboration*, namely, having collaboration ties with individuals in other institutions than the ego scientist's department. It includes a broad category of collaborative relationships, to be more specific, academia-industry relationships, academia-government relationships, inter-university relationships, and interdisciplinary relationships. I focus on collaborators' institutional affiliation rather than their geographic location to explore the boundary-

[8] Because of the difficulties in collecting data on crosscutting relationships for an accurate measure of the "structural hole" concept, a number of studies operationalized this construct by using heterogeneity among network contacts as a proxy (Hoang & Antoncic 2003).

spanning collaboration because I conceive of the heterogeneity in information, resources, norms, and practices is more prominent across instiutional settings and more pertaining to the focal innovative activity. The following paragraphs review the empirical studies on how these collaborative relationships are correlated to innovative outcomes. Note that empirical evidence may be absent or not supportive.

While universities are well known for their scientific breakthroughs and critical know-how, industry has established capabilities in product testing, production, and distribution. Membership in traditionally noncommercial setting suggests academic scientists may be considered as “outsiders” and the best way for them to access resources for commercialization is to borrow (but not build) social capital from critical insiders (Burt, 1998). As such, it is reasonable to expect collaboration with industry would promote academic scientists’ patenting performance. There may be at least five important benefits and influences attached to collaborating with industry: 1) Rich and timely market information for demand identification; 2) Less transaction costs associated with greater knowledge of potential licensees; 3) More tacit knowledge of the entrepreneurial process that is useful to overcome institutional and organizational barriers; 4) Quick access to financial, material, and human resources in companies; and 5) Favorable attitudes towards commercial activities.

In fact, the facilitating effects of collaboration with industry are generally supported. In a study of superstar scientists in biotechnology, Zucker et al (1998) found that 5 articles coauthored by academic ‘star’ scientists and corporate researchers corresponded to 5 more products in development and 3.5 more products on the market. This finding confirmed the association between close academia-industry relationship, formal or informal, and positive innovative outcomes that had been revealed previously (Audretsch & Stephan, 1996; Zucker & Darby, 1996). Another study uncovered that academia-industry ties resulted in an increase of patents in microelectronics (Gulbrandsen & Smeby, 2005). Also, Dietz and Bozeman (2005) reported that higher levels of industry funding were strongly and positively associated with academic scientists' higher patent rates. A study of physicists and engineers in the United Kingdom (UK) and Germany is an exception as it found that collaboration with industry might be driven by research-related motives and did not have direct association with commercialization-oriented activities such as patenting (D'Este & Perkmann, 2011).

Very rare research has been done on the academia-government relationship and commercial outcomes, but implications can still be found. One study reported that those doctoral scientists and engineers in academia with government support had patenting rate almost three times that of their counterparts without government support (11.9 vs. 4.2 percent), although they had lower rate than those with industry support (Strickland, Kannankutty, & Morgan, 1996). Another study, using scientists' employment in government[9] as a proxy for connection to government, reported that such employment experience was negatively related to patent productivity (Dietz & Bozeman, 2005), but the negative relationship did not reach a significant level. In addition, the "Triple Helix" model argues that inter-institutional collaboration spanning industry, government, and university is likely to promote innovative activities (Etzkowitz, 2008; Etzkowitz & Leydesdorff, 2000; Etzkowitz, et al., 2000).

[9] This was a proportional measure calculated by dividing the years in government jobs by the total job years.

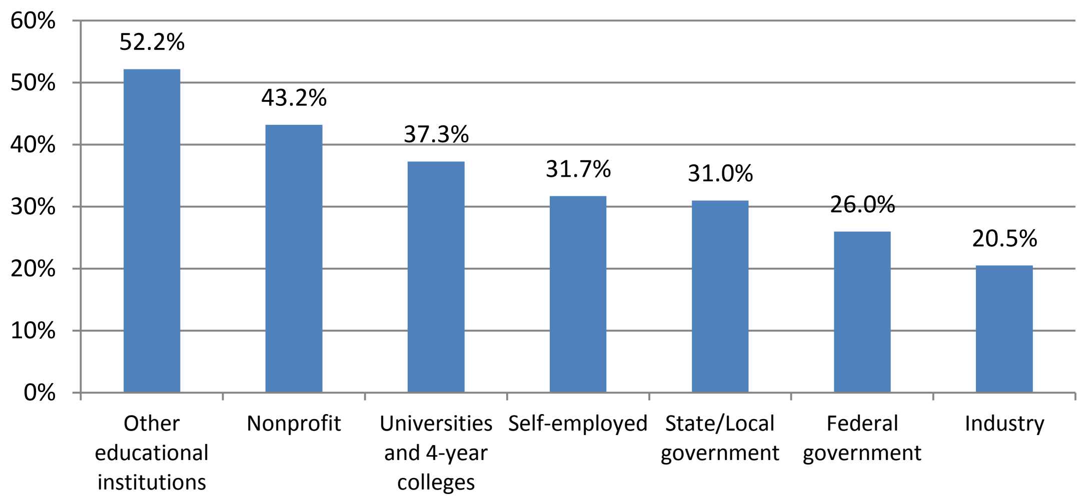
In terms of interdisciplinary collaboration that involves the integration of knowledge from two or more disciplines, research on its association with patenting or general commercial activities is also sparse. However, behind the vast investment in interdisciplinary fields is the strong belief that scientific breakthroughs will be most likely to occur at the interfaces of disciplines (Colwell, 1998; Jones, 2003; Porter & Youtie, 2009; Rhoten & Pfirman, 2007), suggesting interdisciplinary collaboration should facilitate innovative activities and outcomes. Empirically, Thursby and Thursby (2011) uncovered a strong association between being listed in multiple departments and higher patent rates among academic engineers, underscoring the role of interdisciplinary orientation in enhancing patenting behaviors.

To my best knowledge, there has not been any research investigating the direct association of inter-university collaboration and patenting performance, and thus there is no empirical evidence on this regard. Despite the absence of empirical evidence and some counter-expectation evidence as reviewed above, I still hypothesize that, all else being equal, a collaboration network containing one of the four kinds of boundary-spanning collaboration ties would strongly predict better patenting performance as this hypothesis is theoretical derived.

2.2.2.3 Gender, Boundary-spanning Collaboration, and Patenting

As gender is focused upon, the social network research generally speaks to the differences between women and men in forming and using networks. It has discovered that women's network tend to include friends (Hitchcock, et al., 1995), kin ties (Marsden, 1987; Moore, 1990; Renzulli, et al., 2000), and more expressive relationships (Umberson, et al., 1996). In the professional world, women's networks tend to be small, dense, and intimate (Brewer & Lui, 1989), to have greater homogeneity (Ibarra, 1992, 1993), and to have contacts with less power and authority (Brass 1985). One explanation for the gender contrasts is that women have historically been excluded from workplace and thus have problem with legitimacy in the labor forces, especially professional labor forces (Brass, 1985; Burt, 1998; Dasgupta & David, 1994; Griliches, 1990; Stanley, 1993). A second view emphasizes the gendered socialization. That is, because of the way they are raised, women feel more comfortable in a small circle including friends and relatives; and for the same reason, men favor a less intimate and more competitive environment (Macdonald, 1992). A third line of thinking is that the popular ways to network among men do not fit in women's schedule and tastes: men tend to socialize through sports and with people outside of immediate work units whereas women tend to socialize through lunches or dinners during work time with people in current work units (Khan, 1996). This may be largely due to more family responsibilities women assume (Podolny & Baron, 1997). An additional thought is that women usually occupy lower-level positions and this restricts their access and ability to attract social investment from outside powerful people (Ridgeway, 1997).

Those explanations are not exclusive but instead interrelated to each other and reflect what I mentioned earlier the fundamental way of individuals' using stereotyped and unequal gender beliefs to categorize self and the others in all sorts of social activities and guide their expectations and behaviors (Ridgeway 2006, 2007, 2009). Women are still minority in the context of professional labor forces, especially in industry, federal government, and prestigious universities (see Figure 2-1). Along Ridgeway's (2009) reasoning that the gender background becomes more powerful in gendered contexts, female academicians are likely perceived as incompetent and rejected as equal collaborators when they seek for external collaborations. Therefore, they tend not to have boundary-spanning collaboration ties than their male colleagues; and then, given the positive effects of boundary-spanning collaboration on patenting engagement, women's lower level of patenting involvement may be partially due to their less likelihood of having boundary-spanning collaboration ties.



Source: NSF (2011)

Figure 2-1 Percentage of S&E female professionals by employment setting: 2006

As the social capital resided in networks (boundary-spanning collaboration ties here) is contended for professional outcomes, research has brought attention to the contingence of its returns on gender. Overall, evidence is indicative of fewer social capital benefits for women even when they have similar networking behaviors (Brass, 1985; Campbell, Clarridge, Gokhale, Birenbaum, & Hilgartner, 2002; Ibarra, 1992; National Science Board, 2000; van Emmerik, 2006). Explanations can be found in reflections of personal experiences as well as systematic investigations. Burt (1998) found, in a study of nearly 300 managers in large corporations, that women would benefit more from connecting with critical individuals; but the reality that they had fewer collaborators situated in critical positions suggests that women are likely to have a lower level of returns from collaboration than men.

Additionally, Lin (2001) used the concept *Return deficit* to explain the different outcomes by gender with similar networks: 1) women may not use or mobilize the appropriate capital for the instrumental action of attainment given their limited experiences in the work place; 2) even though the appropriate social ties are mobilized, these tied contacts (usually males) are reluctant to invest their capital if they expect women are less competitive and valued; and 3) the response from reward agency may overestimate men's value and underestimate women's. As women's limited experiences may be one reason for the underutilization of their strategic contacts, another possibility is that they feel uncomfortable (guilty or rude) to do so (Walsh & Maloney, 2002). Taken together, Lin's *Return deficit* hypothesis can be extended to have social processes in two scenarios: 1) women don't have critical contacts, and so even with mobilizing efforts, the returns are limited; 2) women have critical contacts, but a) they are reluctant to mobilize,

b) they don't mobilize appropriately, c) contacts are not willing to invest, and/or d) the decision makers devaluate women's capital.

However, there is a second possibility (Ding, 2004). Although the benefits from having boundary-spanning collaboration ties for women may be smaller than those for men, considering women are usually excluded from information and resources exchanges, to the extent that they can access, these benefits are particularly valuable for them. In other words, because women and men have different probabilities of accessing resources, the same amount of resources may have larger marginal impacts on women's professional outcomes than men's. The two possibilities lead to two competing hypotheses: a) women benefit less from having boundary-spanning collaboration ties; and b) women benefit more from having boundary-spanning collaboration ties.

2.3. Nanotechnology: A Strategic Context for Investigation

Besides presenting a different field context and having great potential to be patented, nanotechnology is selected as a focal field here for additional considerations. On the one hand, nanotechnology has seen impressive expansion in the global scientific and economic landscape; and on the other hand, we still know little about it, especially with respect to its impacts on social inequalities in general (Cozzens & Wetmore, 2010; Wood, Jones, & Geldart, 2003; Zucker & Darby, 2005) and gender inequality in particular (Smith-Doerr, 2010). While it is perceived to have both favorable (e.g., more opportunities for collaboration) and unfavorable characteristics (e.g., lower representation of women and ambiguous evaluation criteria) for women's participation and performance, little empirical evidence has been collected and analyzed for a better understanding of women's status in the new field. Then, a tricky question rises as to how these characteristics would interact with each other to affect women's and men's collaboration and collaboration-related outcomes (patenting here).

This section first offers a brief introduction of nanotechnology and its emergence, highlighting its increasing importance in scientific development and national economy. Following that, it presents the arguments and evidence that help validate the importance of academic patenting and the omnipresence of collaboration (including collaboration with industry) in this emerging field. Finally, the distinct characteristics of nanotechnology with respect to gender are identified and discussed, based on which hypotheses regarding gender, collaboration, and patenting performance in nanotechnology are generated.

2.3.1. The Emergence of Nanotechnology

Using the definition developed by the US National Nanotechnology Initiative (NNI), nanotechnology refers to "the science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1-100 nanometers" that includes "research and development of materials, devices and systems that have novel properties and functions due to their nanoscale dimensions and components" (PCAST, 2005). Essentially, nanotechnology allows researchers to manipulate molecular-sized materials for novel properties and functions. The development of scanning tunneling and atomic force microscopy instruments in the early 1980s first signaled empirical research at the nanoscale (Baird & Shew, 2004). Since then, a variety of disciplines (physics, chemistry, biology, materials, and engineering) have contributed to the quick emergence of nanotechnology (NSTC, 1999; Porter & Youtie, 2009).

Nanotechnology is considered as one of the most promising technologies in the 21st contrary with capabilities of providing benefits for further technological and societal development (Kim, Corley, & Scheufele, 2012; Roco, 2004), and has drawn great attention from the scientific community, government, industry, and even the ordinary people around the world. With the perception of nanotechnology's potential, more than 60 countries have developed their own national programs and been involved in a global race in promoting research and innovations in this new field (Huang, Notten, & Nico, 2010; Shapira & Wang, 2010). A series of S&T indicators demonstrate that the U.S. is the global leader in nanotechnology so far. The U.S. was the first country to launch a national nanotechnology program, the NNI, in 2000[10]. Since then the federal funding to support nanotechnology research and development (R&D) soared to nearly $1.8 billion in 2010 and around $12 billion in the first decade of the 21st century (Shapira & Wang, 2010; Shapira, Wang, & Youtie, 2010). In 2004 and 2005, the investment from the U.S. government in nanotechnology accounted the largest share in the world (Hullmann, 2007). Meanwhile, annual investment from the U.S. companies in nanotechnology approached $2 billion, and specifically, venture capital (VC) investment in start-up enterprises engaged in nanotechnology totaled about $590 million in 2006 (Shapira, et al., 2010). The U.S. also has been the most active country in publishing and patenting nanotechnology research (Gatchair, 2010; Huang, et al., 2010).

[10] See information online http://www.nano.gov/html/about/home_about.html

2.3.2. A Strong Orientation towards Commercialization

Since its inception, nanotechnology has seen a strong orientation towards application and commercialization. This trend was promoted by huge public and private investment (Roco, Mirkin, & Hersam, 2011) and has been manifested in various indicators, including the number of new firms, products, and patent applications and grants in this field. Kay & Shapira (2009) estimated that by the year of 2006 upwards of 5,000 corporate establishments in the U.S. had entered the nanotechnology domain (about one-third of the total of all the world's corporate establishments identified as active in nanotechnology through publication and patenting). These establishments ranged from large multinational companies, small and mid-sized firms, to new nanotechnology-focused start-ups. More than 1,000 nanotechnology-based available consumer products were catalogued worldwide by the Project on Emerging Nanotechnologies, including nanotechnology-enabled products in cosmetics, clothing, sporting equipment, electronics, and automotive applications. These currently available nanotechnology-based consumer products represent just a portion of all the nanotechnology applications available today, and an even smaller sub-set of nanotechnology-enabled applications, devices and systems that may enter into use in coming years. This is indicated in the large number of patent applications that have been filed to date, which represents an accumulating stock of inventions that can be drawn upon for future use. More than 17,000 nanotechnology-related patent applications were received by USPTO from 1990 to 2008, with more than 12,600 nanotechnology-related patent grants through to the latter year (Shapira, et al., 2010). VC investment in start-up enterprises engaged in nanotechnology totaled about $590 million in 2006 in the U.S. (Shapira, et al., 2010).

In addition, like in biotechnology, the extensive patenting in nanotechnology has been characterized by a remarkable role of university patenting (Mowery, 2011; Thursby & Thursby, 2011). The large number of nanotechnology patents involving university faculty not only comprise those filed by faculty through their universities but also those filed by firms and listing university faculty as inventors (Thursby & Thursby, 2011). The estimates showed that the U.S. universities held more than 15 percent of all U.S. patents in nanotechnology whereas they simply held less than 2 percent of all U.S. patents in 1975-2002 (Mowery, 2011). Another study reported the patents with at least one assignee being a U.S. university accounted for around 9 percent of total nano-related patents filed through USPTO in 2002-2006 (Meng & Shapira, 2010). Considering a substantial proportion of patents assigned to firms have involved faculty inventors in the field of nanotechnology, the proportion should be even larger.

According to Thursby and Thursby (2011), the scientific discoveries in nanotechnology, like those in biotechnology, represent new methods of inventing, and hence suggest the excludable human capital possessed by faculty inventors. While most of the nanotechnology discoveries are more research tools instead of end products, the involvement of faculty inventors in further commercial exploitation is warranted. Furthermore, Mowery (2011) argued that the extensive patenting behaviors in nanotechnology, including such behaviors in academia, are reflective of the character of "pro-patent era." In spite of the dramatic increase in nano-patents, few of them have been involved in suits or infringement actions, which further encourage the patenting activities. Also, as the organization of nanotechnology innovations resembles that of biotechnology, which involves contractual and collaborative relationships among "vertically specialized" firms, the prominent role of universities in advancing the new technology is expected. Moreover, in a new field like nanotechnology where evaluation has not been standard, patents are important products that can signal working scientists' performance and should be included in their productivity portfolio (Smith-Doerr 2010; Thursby and Thursby 2011). Taken together, nanotechnology presents a field where scientific research tends to be patentable and further commercialized and where patenting and commercial exploitation tend to be incorporated into the evaluation system for academic scientists' performance.

2.3.3. The Collaborative Behaviors in Nanotechnology

Nanotechnology is considered as a field full of interdisciplinary research (Meyer & Persson, 1998; Rhoten & Pfirman, 2007), and being more interdisciplinary over time (Smith-Doerr 2010). In a detailed review of interdisciplinary research (Wagner, Rosessner, & Bobb, 2009), the rise of interdisciplinarity was accompanied with a problem-solving commitment in some science and engineering research and continuous improvement of technology that can monitor much more scientists' work. To address complex problems in reality, interdisciplinary research usually involves multiple researchers with distinct expertise, working collectively as a network or a team to trade and exchange tools, methods, data, concepts, ideas, and/or results around problem-solving projects (Palmer, 1999; Rhoten, 2003; Rhoten & Pfirman, 2007). The complexity of those real-world problems warrants the need for not solely interdisciplinary collaboration that goes beyond the boundaries of traditionally established disciplines but inter-institutional collaboration that spans across institutional settings. As such, boundary-spanning collaborative behaviors are typical in emerging fields (Melkers & Xiao, 2009).

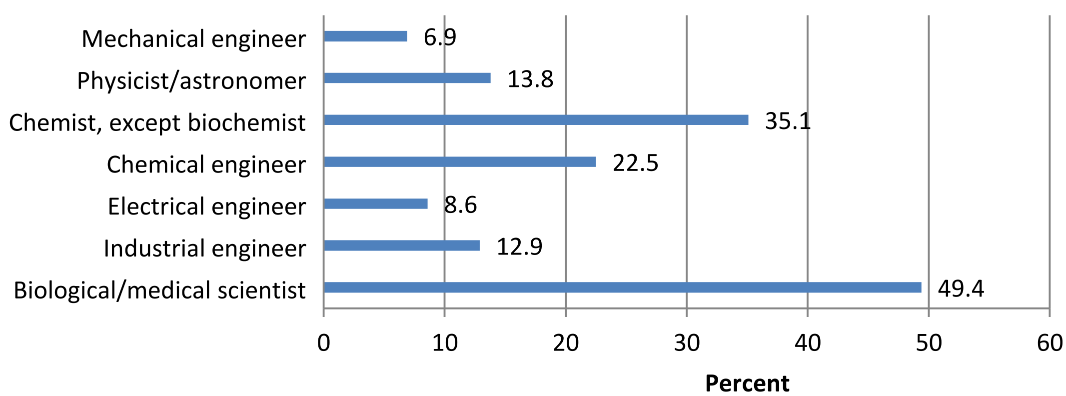
Regardless of some suspicion about the interdisciplinarity and multidisciplinarity of nanotechnology (Schummer, 2004), practices tend to support the existence of a proclivity to collaboration, especially boundary-spanning collaboration, in this field. For example, the development of probe microscopy was evident of intensive university-industry relationships (Mody, 2006; Mowery, 2011). Because of the nature of nanotechnology research (developing tools instead of final products), further commercialization tends to invite faculty's contribution, suggesting more interactions between industry and university in this field (Thursby & Thursby, 2011). Additionally, science and technology policies and requirements from funding agencies usually have clear terms for collaboration in nanotechnology, reinforcing the tendency towards collaboration in this field (Porter, Roessner, & Heberger, 2008; Sargant, 2008). In short, the real-world needs and underlying rationale of policy support suggest a culture in nanotechnology that stimulates and pushes for collaboration, especially boundary-spanning collaboration.

2.3.4. The Relationships of Gender, Collaboration, and Patenting in Nanotechnology

There has been little concrete and reliable information about women's participation and performance in nanotechnology (Smith-Doerr 2010), except one descriptive study analyzing the U.S. patents in nanotechnology by gender (Meng and Shapira 2010). Due to the limitations embedded in the patent data and the descriptive nature, that study is far less than sufficient to answer many questions regarding women's status in nanotechnology. However, research not specifically concerning nanotechnology offers clues for hypothesis development.

On the one hand, some interdisciplinary characteristics of nanotechnology may lead us to assume women are more likely to engage in nanotechnology. For instance, Rhoten and colleagues (Rhoten & Parker, 2004; Rhoten & Pfirman, 2007) suggested that women have a preference for complexity and diversity and thus tend to enter emerging and interdisciplinary fields where diversity is more embraced and opportunities are more available for breaking conventional social rules and research styles. While these fields are premature with indefinite boundaries and ambiguous evaluation processes or standards, the risks associated with a career in these fields may intimidate men rather than women. This is so because women are less likely than men to narrowly focus on pursuing priority and recognition (Barinaga, 1993; Sonnert & Holton, 1995b) and the immaturity may offer a less competitive context for diverse interests and approaches that women appreciate more (Rhoten & Parker, 2004; Rhoten & Pfirman, 2007). Empirical evidence in Melkers and Xiao's study (2009) seems to support these claims as they found that women in fields where they are less represented were more likely to participate in emerging fields.

On the other hand, other features of nanotechnology have the implication that women are still minority in nanotechnology. First, unlike some other interdisciplinary fields such as gender studies, nanotechnology has become scientifically and economically important, and substantial reputational and material benefits linked to the engagement should attract male scientists as well. Second, scientific fields from which scientists are most likely to make transition to conducting nanotechnology are predominantly represented by men, suggesting an extraordinarily small pool of female scientists as nanotechnology participants. The data in Figure 2-2 provide support for this point. In this figure, the scientific fields are listed top-down in an order of a higher to lower probability of which the research in that field can be nanotechnology related (using the ordering created by Porter and Youtie in their bibliometric analysis of the "closeness" of established disciplines and nanotechnology). It can be seen, while material engineering and physics are "closest" to nanotechnology, women only accounted for around 7 and 14 percent of the total scientists in these two fields in 2006; and as women's share was almost equal to (but did not exceed) men's in biology and medical sciences, these fields seem to be distant from nanotechnology. Therefore, the reality may be women are underrepresented in nanotechnology to an even greater level.



Source: Porter and Youtie (2009) and NSF (2009: Table H-5), reorganized by the author

Figure 2-2 Women's representation in the major fields closer to nanotechnology

Based on two assumptions: 1) individual scientists are rational and thoroughly assess the disadvantages and advantages before making the transition to nanotechnology, and 2) unfavorable characteristics of nanotechnology serve as a critical threshold for participation (or decision on participation), I expect only successful scientists, whether women or men, on main achievement measures, including well-situated in collaboration, would decide to enter the field. As a result of the selection process, female and male scientists working in nanotechnology are likely to have a similar level of boundary-spanning collaboration. Accordingly, I hypothesize:

H2: The presence of boundary-spanning ties in scientists' collaboration networks does not differ by gender.

Given the strong and positive relationship between boundary-spanning collaboration and patenting performance as elaborated earlier, although the gap between genders in having boundary-spanning collaboration ties may be very small, the gender differences in network returns may, at least partially, lead to gender differences in patenting. As the network returns are particularly concerned, there are two possibilities which can be formally stated as:

H3a: Women benefit less than men from having boundary-spanning collaboration.

H3b: Women benefit more than men from having boundary-spanning collaboration.

Drawing on Ridgeway's (2009) account of the interaction between gender background frame and institutional context and the deducible scenario that nanotechnology is even gendered with even lower representation of women, I expect *return deficit* (H3a) to be revealed on all the boundary-spanning collaboration measures, but still keep both hypotheses open for empirical tests.

2.4.Theoretical Framework Building

Figure 2-3 illustrates the conceptual framework that integrates the relationships between key and relevant variables. The bold solid lines represent the hypothesized relationships to be tested. These are the direct effect of being female, the direct effects of the various boundary-spanning collaboration relationships, and the indirect effect of being female through boundary-spanning collaboration on patenting performance. Relevant variables will be specified as controls to assure comparisons are made between scientists who have similar resources and standings.

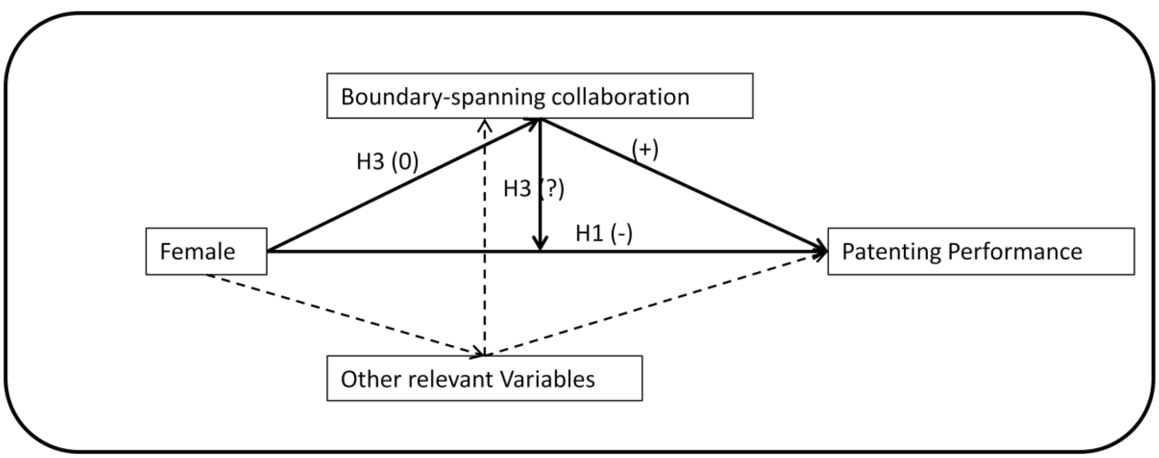


Figure 2-3 Overall theoretical framework

3. DATA AND METHOD

3.1. The General Design

To address the research questions and hypotheses in chapter 2, this dissertation relies on two approaches that have been separately used in previous research on gender and patenting, that is, the analysis of large-scale patent records (Frietsch, et al., 2009; Mauleón & Bordons, 2009; Meng & Shapira, 2010; Naldi, et al., 2004) and the analysis of data collected from a relatively small sample through survey (Ding, et al., 2006; McMillan, 2009; Whittington & Smith-Doerr, 2005, 2008).

The informatics approach using large-scale patent data has been developed and applied for many research inquiries, including assessing the effects of academia-industry collaboration on technological development (e.g., Hara, et al., 2003; Meyer & Bhattacharya, 2004; Swede, 2003) and tracking the developmental trajectory of new technologies like nanotechnology (Nelson, 2004; Schummer, 2004), and recently has attracted increasing applications on the subject of gender and patenting. This approach fascinates me because it is almost the only means of highlighting distinct features of nanotechnology (Meng & Shapira, 2010; Porter, Youtie, Shapira, & Schoeneck, 2008) and obtaining general ideas about the working scientists and their innovative performance (even only at the aggregate level) in this new field. Nanotechnology emerged as an interdisciplinary field containing expertise from multiple disciplines (Porter & Youtie, 2009) and has not been well established organizationally, which poses a big challenge to accumulating knowledge about it. Pertinent to the current project, while accurate and reliable demographic and other information (including gender) of scientists working in nanotechnology are not available yet, the informatics method is appropriate to help understand the distinctions of nanotechnology (compared to the overall S&T field) in terms of patenting activities, collaborative activities, and women's representation.

In spite of being valuable to obtain general information about the new technological fields, informatics method has limitations in understanding micro-level social dynamics (Bok, 1982; Bozeman & Corley, 2004; Fabrizio & DiMinin, 2008). While this is an issue for this study that has special interest in understanding the role of collaboration in differentiating women's and men's patenting performance, I also incorporate the other approach. Accordingly, the second part of the current empirical work is to perform explanation-pursuing analyses on data collected from a national representative survey. The purpose for this set of analyses is to test the hypotheses developed in Chapter 2 to understand how the gender pattern in collaboration may be different and how the gender effects on patenting may be differentially mediated by collaboration in nanotechnology. Since this survey data contain unique information about academic scientists' collaboration network and a previously unavailable survey instrument that could be taken as a measure of informants' participation in nanotechnology, they allow me to investigate the above core relationships in detail. In fact, the second part of analysis and its results are more important as they provide more detailed information and implications for further actions to research and address the inequality issue in the new contexts of science.

In the rest of this chapter, for each approach I first describe the data sources, then present the ways in which data were extracted and manipulated, explain how indicators and variables were selected or constructed, and finally discuss and justify analytical methods.

3.2. Patent Data Analysis

3.2.1. Data Sources

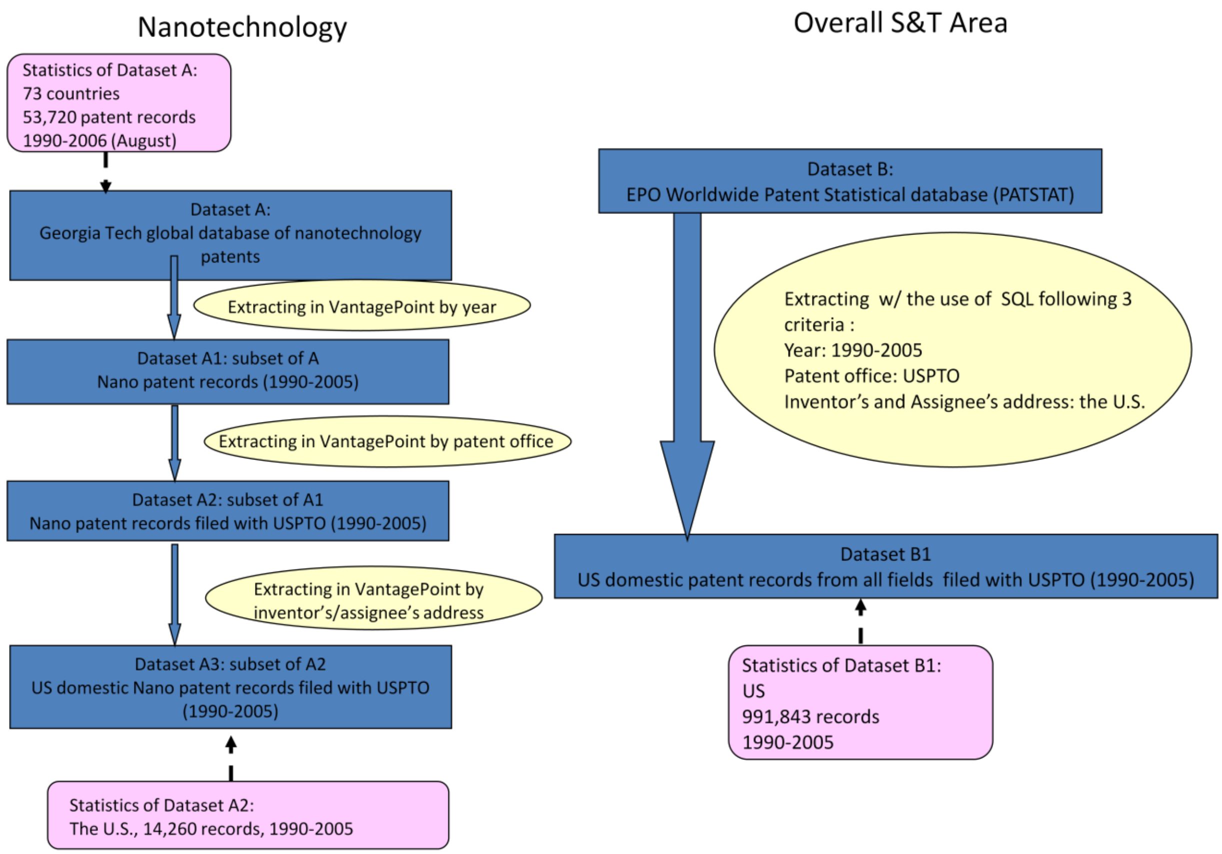


Figure 3-1 The selection process of patent data for this study

Data for patent analysis came from two large patent data sources, and Figure 3-1 illustrates the data selection process. The patent records representing the field of nanotechnology were drawn from the global database of nanotechnology patents developed by the Nanotechnology Research and Innovation Systems Assessment Group at Georgia Institute of Technology (Georgia Tech), Atlanta, the U.S. This database includes patent records identified from different patent sources[11] by applying defined key terms of nanotechnology in search and cleaning. This process was described in the article of Porter, Youtie, Shapira, and Schoeneck (2008). While the article provided many technical nuances (including those of processing bibliometric data), the critical steps for nanotechnology patent search and cleaning are summarized in Appendix B as a reference for a basic understanding of the patent data in this particular database.

The entire patent database resulted from this process contains 53,720 patent records, including patent applications and grants, which had been maintained in more than 73 countries during the period 1990-2006 (August). In order to fully utilize the data, I decided to use data from all years in the database except for year 2006 as the whole year patent records in that year were not available. Given the focus of the current empirical work on the U.S., only patent records published through the USPTO were selected. To ensure that patents were inventions involving the U.S. scientists, only those having inventor(s) or assignee(s) located in the U.S.[12] were kept for further analysis. In other words, foreign patents without any inventor resided in the U.S. applied through the USPTO were excluded. The data selection and cleaning were undertaken step by step in

[11] These sources include MicroPatent database, US Patent and Trademark Office (USPTO), European Patent Office (EPO), Japanese Patent Office (JPO), World Intellectual Property Office (WIPO), patent offices of Germany, Great Britain, and France, and the EPO's raw data resources (INPADOC)

[12] The current focus is on the gender pattern among scientists in the US, but patents filed with USPTO may come from other countries. The restriction is applied to minimize the noise from foreign patents.

the software program VantagePoint[13] and illustrated in Figure 3-1. To summarize, I first selected patent records published in the period 1990-2005, kept only those published through USPTO, and finally restricted to those having at least one inventor located in the U.S. The finally obtained subset consists of 14,260 patent records.

The patent records coming from EPO Worldwide Patent Statistics Database (PATSTAT) represent patenting information in the overall S&T area. The PATSTAT database was well organized, maintained, and updated in Fraunhofer Institute for System and Innovation Research (ISI) in Germany. To ensure the patent records selected from this database have the same key characteristics (inventions involving the U.S. scientists that published through the USPTO between 1990 and 2005) as those in nanotechnology for the comparison purpose, the same selection criteria for nanotechnology patent selection were also applied here, that is, published in the period 1990-2006, through USPTO, and with at least one inventor and assignee being located in the U.S.

Unlike what was done with nanotechnology patents, the initial data searching and extraction were undertaken in the Fraunhofer ISI data management system with the use of SQL commands (one example is given in Appendix C). This was so because the original PATSTAT data were stored in that system and managed through SQL commands. The extracted records were first saved in text files and then transferred into VantagePoint program for further use. To avoid the loss or messing up of the information in the transfer process, a random sample was selected and, for each individual record in the sample,

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[13] VantagePoint is a powerful text-mining software developed by Georgia Institute of Technology for discovering knowledge in search results from patent and literature databases. More information about this program is available online http://www.thevantagepoint.com/

information in the text file was compared with its corresponding piece in VantagePoint program. After many rounds of verification and correction, the final dataset consists of 991,843 patent records. I did not exclude the nanotechnology patents from this set of patent records before making comparisons because: 1) I would take the patents in the broad category as a benchmark that "averages" the developmental trends of different fields and reflects the general change in the technological world; and 2) the scale of these two datasets suggests patents in nanotechnology only account for a very small part of all patents in the U.S. (especially in the period 1990-1999) and can hardly change the general pattern.

3.2.2. Identifying Inventors' Gender

The gender information of inventors has not been recorded in patent databases yet. Therefore, as part of the research, systematic operations had to be performed to identify inventors' gender to avail the patent data for the gender-based analysis. Following the approach adopted by Naldi et al. (Naldi, et al., 2004; Naldi & Parenti, 2002) and Frietsch et al. (2009), I developed a first name database and used it for gender classification in a preliminary study (Meng & Shapira, 2010). For the current research, a gender-segregated first name list provided by a German computer journal called C't Magazin[14] was integrated to extend the name database developed before[15]. What should be especially

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[14] The list can be downloaded from http://www.heise.de/ct/ftp/07/17/182/. It was developed for a computer program that can help identify gender of popular European, American, Japanese, Indian, and Chinese names.

[15] Before integrating the name list to the existing name database, I removed many duplicated first names as they were coded in different genders in different European countries. Compared to the old name database that contained 2,440 unique first names (female 756 and male 1,684), the extended one contains

mentioned is that the extended name database includes quite a few Asian originated names and thus allows for identifying the gender of scientists of Asian origins.

As it is of the most concern the accuracy and reliability of the method in classifying Asian names into corresponding gender groups, verification was conducted by using the created name database to check 100 Asian faculty members in Georgia Institute of Technology[16]. As a result of the check, 46 Asian faculty members were classified by the newly developed name database (15 female and 31 male names), among which 36 faculty members' gender was correctly identified. Although the accuracy is still low (only 36 out of 100 scientists can be correctly identified), this is an improvement from the state that all scientists with Asian originated names had to be excluded from analysis. Given that scientists of Asian origins have been active and kept increasing in the U.S. technological community (Kerr, 2007) and the gender pattern in this group may not be the same as that in Caucasians (Hanson & Meng, 2008), this improvement manifests the efforts in correcting the bias towards Caucasian pattern in the analytical results. Of course, this is a premature version for Asian scientists' gender identification but it sets a basis for further improvement.

Then, two thesauri, one being female names and the other male names, were created based on the new gender-segregated first-name database for matching process in

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33,468 unique first names (female 16,088 and male 17,380). Many Korean and Chinese names that could not be identified in the previous study have their gender codes in this new name database.

[16] The list of faculty members in Georgia Institute of Technology is available online (http://www.catalog.gatech.edu/general/adminfac/ag.php) and the seemingly Asian names are easily verifiable by checking their background information, usually their undergraduate universities/colleges, available in their personal webpages or CVs.

the VantagePoint program. Matching[17] in this project was a two-step procedure: first, using the “female” thesaurus, the software marked out those names/inventors appearing in the thesaurus; and then repeated this matching and marking-out when applying the “male” thesaurus. Consequently, some names/inventors were not marked as either “female” or “male;” a few names were classified as both female and male (these usually have two or more parts (e.g. Young-Jin) and some part was identified as female while the other as male). For these cases, I went further to find out the gender information by hand using an authoritative online tool[18] developed by Geoff Peters of Simon Fraser University. With the help of the online name guesser, I could know the probability of a first name to be female (and also male), and based on the probability I assigned those unambiguous names to appropriate gender group[19]. As a result, around 93 percent of nano-patents and 99 percent of patents in the overall S&T area have all or part of their inventors to be assigned to corresponding gender groups. With the high rate of identification, I have more confidence to draw implications from these patents and their inventors.

3.2.3. Indicators and Method

The methodological approach for the patent analysis is descriptive. Indicators measuring the growth of patents, the patterns of collaboration, and women’s relative to men’s representation were constructed and applied to the two sets of patent records, and

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[17] The matching procedure was only applied to the nanotechnology patent database. The gender information was available in the PATSTAT database stored in Fraunhofer ISI after applying combined name lists from Frietsch and peers (2009) and C’t Magazin for the sex identification. And in extracting patent records from that database, the gender information of inventors were extracted as well.

[18] http://www.gpeters.com/names/baby-names.php

[19] Only the probability of a name to be female (or male) is larger than 60% did I assign the informed gender to that name; otherwise (around 50%), I mark the name as unknown.

the results in nanotechnology were compared with those in the overall S&T area in order to know more about the distinctions of nanotechnology. What these indicators measure and how they were constructed are listed in Table 3-1 and explained in the paragraphs that follow.

Table 3-1 Indicators for patent analysis

Indicators	How they are constructed
Annual growth rate	*Aggregate-level indicator:* The total number of patent outputs of a given year is subtracted by the total number of previous year, and the difference is divided by the total number of previous year and then multiply by 100
Team size	*Patent-level indicator*: The total number of inventors of a patent
Average team size	*Aggregate-level indicator*: The sum of team size of all patents divided by the total number of patents for each year and each field
The proportion of collaborative patents	*Aggregate-level indicator*: The number of patents that have two or more inventors to the total number of patents for each year and each field
Gender ratio	*Aggregate-level indicator*: The number of female inventors to male inventors in each field
Participation	*Patent-level indicator*: Whether a patent involving at least one scientist from a given gender group
Contribution	*Patent-level indicator*: The share of scientists from a given gender group in a patent team
Women's relative participation	*Aggregate-level indicator*: The sum of women's participation divided by that of men's for each year and each field
Women's relative contribution	*Aggregate-level indicator*: The sum of women's contribution divided by that of men's for each year and each field

The *annual growth rate*, tracking the rise of nanotechnology in the technological landscape, was calculated by using the formula $R_i=(C_i-C_{i-1})/C_{i-1}*100\%$, where R_i denotes the growth rate for year i, C_i denotes the patent counts for year i, and C_{i-1} denotes the patent counts for year before i.

Indicators for collaboration include *average team size* and *the share of collaborative patents*. The *average team size* was derived by summing up the *team size* of patents and dividing it by the total number of patents in each of the sixteen years. While this measure is an aggregate one at the year level, it is not useful to differentiate independent and collaborative patents. To address the problem, the other indicator, *the share of collaborative patents,* was created by dividing the total number of patents with two or more inventors by the total number of patents in each year. The patterns shown with these two indicators should inform us whether the level of patents being collaborative products in nanotechnology was higher than the general level in the studied period.

Three indicators, *gender ratio*, *women's relative participation*, and *women's relative contribution* were used to indicate women's and men's representation in patent outputs. *Gender ratio* is straightforward, calculated by using the total number of women and men inventor observations in the two patent sub-datasets. The two relative measures were further constructed from two indicators – *participation* and *contribution* – that were originally developed by Naldi and peers (Naldi, et al., 2004; Naldi & Parenti, 2002) and used in other similar studies to investigate the gender pattern in patenting (Frietsch, et al., 2009; Mauleón & Bordons, 2009, 2010; Ejermo & Jung 2012). *Participation* refers to the count of patents involving at least one scientist from a given gender group ("full count").

For example, among 5 inventors for a patent, 2 are female and 3 are male. Then, the participation of female is 1 and that of male is also 1. If all inventors are female, male's participation is 0. *Contribution* refers to the "fractional count" of gender with the basic assumption that each inventor made equal contribution. Considering the first example, the contribution of female is 2/5 and that of male is 3/5. As in this study the comparisons at two levels, the gender level and the field level, make it difficult to read and interpret the value of participation and contribution for each gender group, two *relative* indicators were generated. *Women's relative participation* was created by dividing women's *participation* by men's in each year. As for *Women's relative contribution*, I first calculated women's and men's *contribution* at the patent level and summed them up by year separately, and then divided women's annual *contribution* by men's annual *contribution*.

3.3. Survey Data Analysis

3.3.1. The Main Source: NETWISE Survey Data

After gaining some general impression about nanotechnology, I move to use survey data to obtain the understanding specifically about the interrelationships of gender, collaboration, and patenting performance in nanotechnology at the micro-level. Here I consider a "typical" scientist in the scientific community to identify the unique characteristics of scientists in nanotechnology, but focus more attention on the nanotechnology group to investigate the key relationships. The data are drawn from a major national study of academic scientists in the U.S., funded by the U.S. National Science Foundation "Women in Science and Engineering Network Access, Participation, and Career Outcomes" (NETWISE) (Grant #REC-0529642 and Co-PI's: Dr. Julia Melkers and Dr. Eric Welch)[20].

The survey sample of 3,677 individuals was randomly drawn from the population of academic scientists and engineers in six disciplines (biology, chemistry, physics, computer science, earth and atmospheric sciences/EAS, and electronic engineering) in 150 U.S. Research I universities. The sample was stratified by gender, rank, and discipline, and the selection of these disciplines was based on the level of women's representation (low, transitioning, and high fields). The initial invitation and follow-up reminders were sent to individuals in the sample by traditional mail, but the survey was implemented online using Sawtooth Software. 1,598 usable responses were finally received (44% response rate). Responses were fairly evenly distributed across the six disciplines (around 18% from EAS, 17% from biology, chemistry, and physics, 16% from computer sciences, and 13% from electronic engineering) and genders (48% women) but a little skewed towards senior ranks (27% assistant professor, 28% associate professor, and 45% full professor).

As mentioned earlier, this NETWISE dataset contains unique information about faculty scientists' collaboration, including that of their collaborators and the relationships with collaborators. More specifically, using an ego-centric network design, the survey included a series of *name generator* and *name interpreter* questions to gather detailed data on respondents' relationships with individuals they named as closest collaborators and advisors. Five name generator questions asked respondents (egos) to provide the

[20] More details can be found in the project website: http://netwise.gatech.edu

names of collaborators and advisors (alters) in their research collaboration, advice, and support networks, including the 1) closest collaborators in their own university and 2) outside their university over the past two years, 3) individuals with whom they regularly talk about research but have never formally collaborated, 4) individuals from whom they seek advice about career and professional development, and 5) individuals with whom they regularly talk about important university or department related issues. By the end of the survey 12,727 names were identified from the name generator questions as closest collaborators, informants, professional advisors, and individuals with whom the respondents talked about important department or university issues.

The name interpreter questions collected information about the relationship between the ego and each alter, such as origin of acquaintance, closeness of research expertise, communication frequency, and the type of their collaboration, as well as the background of each alter. Therefore, in addition to individual demographic information, research activities, publication productivity, teaching and administrative responsibilities, and perception on institutional environment, the NETWISE dataset contains rich information about the respondents' knowledge exchange activities and contents in the exchange with those named individuals.

Although the main purpose of the survey was not specific to study scientists' engagement in nanotechnology, respondents were asked whether they "are currently conducting funded research in a recognized area of emerging technology." There was a list of emerging technology areas in the survey drawn from the updated (at the time of the survey) list of "top ten emerging technologies" identified by *Technology Review* (please find more details in Melkers & Xiao, 2009). If respondents confirmed that they were funded in an emerging technology area, they were asked to further specify the emerging areas. Finally, 173 nano-scientists were as having been funded in specific areas of emerging technology in the two years prior to having received the survey. Respondents were asked to indicate in which of a set of areas of emerging technology they had been funded. Those indicating nano-technolgy areas were coded as nano-scientists[21]. I created a variable in the dataset to distinguish those conducting funded research in nanotechnology from those not for following analyses. It has to be noted this survey instrument may be biased against those who engaged in nano-related research but not funded by “nano-titled” grants (e.g. nanotechnology may serve as an important tool for another research inquiry). However, while this point should be kept in mind when reading final results, this instrument does provide a useful and straightforward way of identifying scientists involved in nanotechnology.

3.3.2. Collecting Additional Data

The survey was not intended to study scientists’ patenting activities either, and the patenting performance information was not available in the original dataset. However, thanks to the availability of detailed identification data, I was able to search and collect patent application information from the USPTO patent database. As the endogeneity issue was always mentioned but not well addressed in previous research on collaboration and scientific productivity, I dealt with it by purposively treating collaboration as an

[21] nanophase, nanoscale patterned media recording, nanoparticles, nanoparticle fabrication, nanomaterials for bio-engineering, nanomaterials, nanomanufacturing, nanomagnetism, nanolithography, nanogeosciences, nanofluidics, nanoenhanced bioanalytical chemistry, nanoscience, nanoscale photovoltaics, nanotechnology, nanotechnology and materials, nanotoxicology, nanowires and sensors, active nanostructures and nanodevices, semiconductor nanomaterials, carbon nanotube sensors, carbon nanotubes, and MEMS and nanotechnology

exogenous variable, that is, search patents filed in year 2006-2010[22] after the collaboration data were collected (2006). As the 5-year window is quite short for sufficient cases to have patent applications to be granted (given the thorough substantial examination[23] that spans at least 12 months), I decided to use all possible patent applications (rather than those have been granted patent rights) to increase the instances that had ever filed a patent in this sample.

To start the manual search procedure, the precise spelling of faculty respondents' names had to be confirmed. I first searched these respondents through Google using the available information in the survey database including their names (even incorrect or ambiguous) as well as the university and department they were affiliated when the survey was conducted in 2006. After ensuring a webpage to be a focal scientist's personal webpage, I recorded the webpage and downloaded the Curriculum Vitae (CV) whenever available for future information verification. Then, I compared a scientist's name listed in his/her personal webpage, his/her publications (publication information can be found on his/her webpage or CV), and the dataset. If they were not identical, I made the choice based on four criteria – most frequently used, officially used, currently (2006-2010) used, and with a complete spelling (e.g. Mary Ann Liebert instead of Mary A. Liebert) – and recoded the choice for the following patent search.

[22] 2010 is the most recent year that the whole year patent data were available when the dissertation research conducted

[23] http://www.wipo.int/sme/en/faq/pat_faqs_q4.html and http://www.uspto.gov/patents/resources/general_info_concerning_patents.jsp

In the name check procedure, I found a small proportion of faculty scientists changed their jobs during the period 2006-2010. While 54 of them simply changed their organizational affiliations (whether within or outside of academia), 20 were no longer active researchers for various reasons (died, retired, promoted to managerial/administrative positions, moved to other countries, or left the scientific profession without tenure). The patent records of the latter group were apparently incomplete as their scientific careers were terminated at some point in the focal time frame, and thus they were excluded for later analyses.

Patent application records of these faculty respondents were searched manually through USPTO patent application database[24]. I first used the combination of time (01/01/2006 ~ 12/31/2010) and a respondent's name as key terms for the search, and if any applications were listed as a result, I compared the critical information in each patent application document (including the area of the invention, the possibly matched inventor's name and address, and the assignee's name) with that collected from the scientist's personal webpage or CV to judge whether a patent application belongs to the focal scientist. If the answer was yes, I downloaded the patent document and recorded the patent publication number in a separate file containing names and ID numbers of all active faculty scientists in the NETWISE survey.

For respondents who have middle names, more than one combination of search terms were used in the search (Last+First, Last+First+MiddleInitial, and Last+First+MiddleFull). Only until possible name combinations for a faculty respondent

[24] http://appft1.uspto.gov/netahtml/PTO/search-adv.html

were exhausted in the search did I move to the next respondent. After the first round of search, a research fellow in the School of Public Policy at Georgia Tech repeated the whole manual search procedure on 40 selected cases (20 randomly selected from those who had a high possibility of patenting and the other 20 from those who were less likely to patent). The major problem identified from this verification was the skip of some combinations of scientists' names. To minimize the errors, another round of search was taken primarily for those who have middle names (N≈1,000). And the second round of verification on randomly selected 20 cases indicated the rate of error reduced to zero.

Finally, the result of the manual search indicates that 258 scientists filed at least one patent application between 2006 and 2010, accounting for about 16.4 percent of the sample. The percentage of faculty involved in patenting varies in previous studies: about 35 percent of 4,621 faculty scientists at 11 major U.S. universities had ever disclosed their inventions over 17-year period (Thursby and Thursby 2005); 12.2 percent of 3,862 life scientists had ever patented during the time from their receipt of doctoral degrees to 1999 (Azoulay et al. 2007); 25 percent of 1,084 life scientists had ever patented up to the year 1999 (Whittington and Smith-Doerr 2005); 40 percent of over 2,200 scientists who either published or patented between 2002 and 2005 had applied for at least one patent in the United Kingdom (UK) and Germany (Haeussler and Colyvas 2010). Compared with those percentages, the one revealed in this particular sample is relatively low. But it is still acceptable given that it indicates faculty scientists' patenting behaviors within a five-year period (not in a career-long period).

Table 3-2 The distribution of patenting scientists (2006-10) by discipline

	Biology	Chemistry	CS	EAS	EE	Physics	Total
Total N	275	275	253	288	207	273	1571
Patented (%)	10.2	27.6	20.2	2.1	32.4	11.0	16.4

Note: CS – computer science; EAS – earth and atmospheric sciences; EE – electronic engineering

Looking at the proportion of faculty scientists with patent application(s) in the focal period (2006-2010) in each of the six disciplines, I found that faculty members in electronic engineering and chemistry had higher rates of patenting (32.4 and 27.6 percent respectively), followed by those in computer sciences (20.2 percent). The rate of being involved in patenting was similar among faculty in physics and biology (11.0 and 10.2 percent respectively), and faculty in EAS had the lowest level of patenting (only 2.1 percent). The small rate of patenting involvement in the EAS group suggests the research in this field is unlikely to be commercialized (none of the 4 scientists in this group who engaged in nanotechnology had ever patented), and so I excluded the scientists in this discipline (N=288). Finally 1,283 individual scientists were included for the analysis regarding collaboration network pattern and patenting performance, among which 252 (or 19.6 percent) had patent application(s) in the period between 2006 and 2010. Correspondingly, 7,876 individuals were identified as closest collaborators of these scientists within or outside of their institutions.

Since the literature suggests that university-level variables indicative of organizational culture regarding academic entrepreneurship are of importance for understanding individual faculty scientists' patenting activities (Stuart et al. 2007; Ding et al. 2006), I searched information about TTO and patent applications in the year 2005 for each university in the final sample from Association of University Technology Manager Licensing Survey (AUTM, 2007)[25]. As a result, among the 150 universities, 121 (about 81%) had an active TTO by 2005 and patent application stock in 2005 ranged from zero to 601. The entire process of data cleaning and collection is illustrated in Figure 3-2.

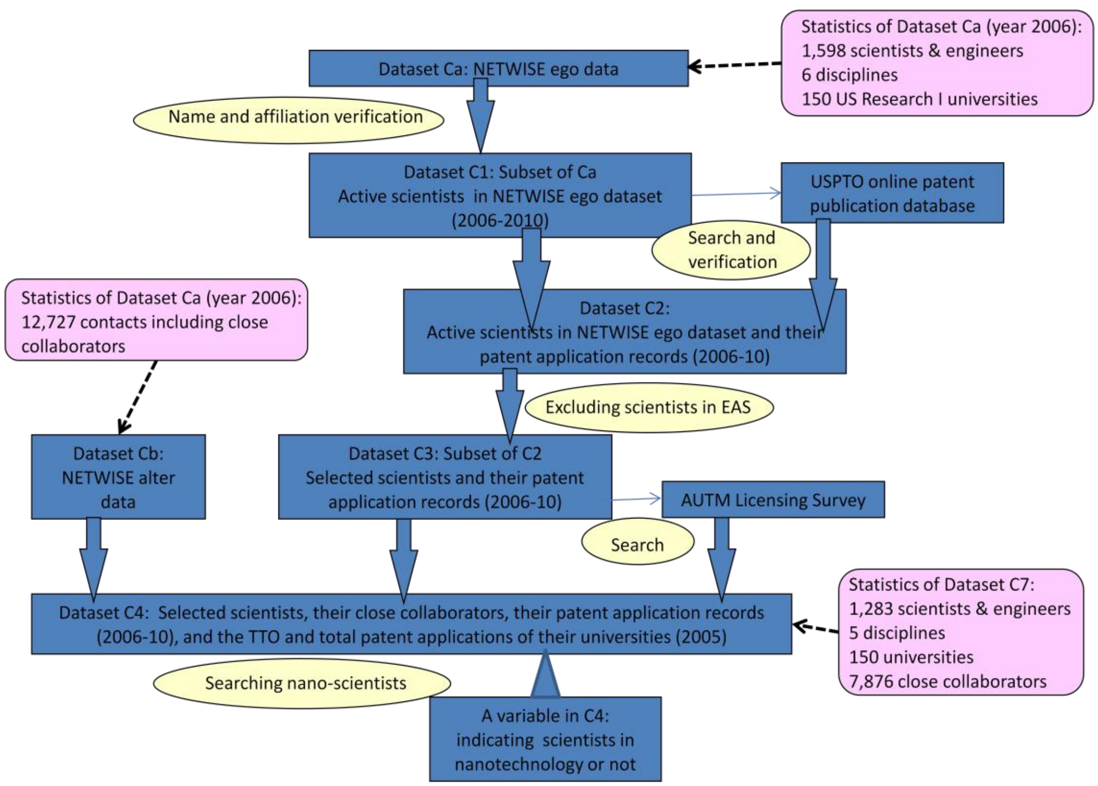

Figure 3-2 Manipulate and Extend the NETWISE survey data for this study

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[25] For those universities that were not listed in the AUTM report, *TTO2005* was set to be 0, and patent applications were searched through USPTO patent application database by using university names and then summed up to obtain the value for *PatentApp2005*.

3.3.3. Key Variables

Patenting Performance. With the patent application information available, one dummy variable *Patenting Involvement* was created to indicate whether a scientist filed at least one patent application during the five-year period 2006-2010. A second measure, *Patenting Productivity*, was constructed to indicate the total counts of an academic scientist's patent applications in the focal time frame. The first task is to gauge the hypothesized gap between genders on patenting performance in nanotechnology, and comparisons were made on the means of the two patenting performance measures by gender. Because the variation on *Patenting Productivity* was very small, this variable was only included in the descriptive analysis. *Patenting Involvement* was not only included in descriptive analysis but was included as the dependent variable in the multivariate regression analyses. Overall, among the 1,283 scientists in this sample, approximately 20 percent had patented in the 5 years; and among those who patented, the patent applications ranged from 1 to 30, with the mean being around 3 and standard deviation (S.D.) around 4.

Gender and Collaboration Network. The primary analytical variables in the models are respondents' self-report sex (*Female*) and those indicating the degree of boundary-spanning relationships contained in their collaboration networks. Approximately 45 percent of the scientists in this sample are female scientists. Assuming different institutional settings provide different resources and knowledge for knowledge's creation and commercial exploitation, I operationalized boundary-spanning collaboration by using collaborators' affiliation information. The data section informed that 7,876 individuals were identified as close collaborators of the 1,283 academic scientists in the sub-sample.

According to their organizational affiliation, a collaborator might be internal falling into one of two categories – working in the same department or a different department; or external falling in each of the five categories: (1) university, (2) federal lab or agency, (3) other government or non-profit organization, (4) industry, and (5) foreign university or research institute. I created four dummy variables to indicate whether an academic scientist in the sub-sample had one or more collaborators in industry (*Industrial ties*), government (*Governmental ties*), other universities including foreign universities (*Inter-University ties*), and other departments (*Interdisciplinary ties*). Because previous research suggests that network size is a proxy of social capital of diversity, I include the total count of each academic scientist's collaborators (*Collaboration network size*)[26] to reveal the relative importance of size and type. Moreover, interaction terms were created to test whether the effects of the collaboration network variables have differentiated effects on patenting involvement by gender as hypothesized. In this sample, academic scientists' collaboration network size ranged from zero to 10, with around 10 percent having industrial ties, 19 percent governmental ties, 71 percent inter-university ties, and 42 percent interdisciplinary ties.

In the multivariate analyses, relevant variable indicating academic scientists' experiences, positions, scientific achievement, and organizational environment were

[26] The squared term of this measure was created and tested for model building, but there was little significant difference between results from models with and without the square term. Thus, in the final report, I do not include it in the models.

specified to allow for assessing the net effects of the key variables on patenting involvement. The following paragraphs provide conceptual justification on the inclusion of these variables and describe how they were constructed.

Boundary-Spanning Experiences. Arguably, activities spanning institutional, organizational, and disciplinary boundaries may expose academic scientists to conditions conducive to patenting. For instance, a scientist working in industry before is much more likely to be familiar with the patent application process as the possibility of being involved in company patent application is high. In addition to the potential opportunities of having access to and information about patenting procedure, individuals with diverse work experiences are expected to be more open-minded and thus more inclined to explore new career paths, like patenting and other commercial activities. In brief, these experiences may allow individual scientists to absorb knowledge and access resources from more and diverse sources for integration and creation; and also they might provide a wider range of potential collaborators where the current collaborative relationships were developed. In either way, these experiences tend to affect collaboration network formation and patenting involvement, and tend to systematically vary by gender (women are less likely to have job mobility and such boundary-spanning experiences).

These experiences are measured through whether a respondent scientist had held 1) a postdoctoral appointment (*Postdoctoral appointment*), 2) full-time employment in industry (*Prior industry employment*), 3) full-time employment in a public organization including government agency (*Prior government employment*), 4) a formal joint appointment with another academic department (*Joint appointment*), and 5) membership with a permanent S&E laboratory or center (*Lab/Center affiliation*). These are all dummy variables with 1 indicating the occurrence of the event. In this particular sample, around 69 percent had a postdoctoral appointment, 9 percent and 15 percent had ever been employed fulltime in industry and public organization respectively, 17 percent had held a joint appointment, and 24 percent had membership with a lab or a center.

Academic Rank. The life cycle theory contends that incentives to undertake scientific research vary over the career life (Levin & Stephan, 1991). As patenting in academy has not been a widespread standard requirement for tenure and promotion, many scientists (especially junior faculty) may be reluctant to engage in commercial activities. By contrast, senior faculty scientists may feel much safer to reallocate their efforts towards commercial activities for income generation and additional reputation. A competing argument is that younger generations among faculty scientists tend to engage in commercial activities like patenting as these activities have increasingly gained the legitimacy in academic science. The same arguments can also apply to scientists in high (versus low) positions. Seniority not only implies different effects on patenting involvement, but means more collaboration ties (including boundary-spanning ties) accumulated over time and high positions attract collaboration. Together with the general finding that women are overrepresented in the junior faculty located in low positions (Mowery, 2007), these suggest the necessity of including academic rank variables to hold fixed the potentially different effects of academic rank on collaboration formation and patenting performance.

To capture the variation among scientists at different career stages, I consider the number of years since a scientist earned his/her Ph.D. until 2006 when the survey was conducted (*# of years since Ph.D.*)[27]. In this sample, only 1,276 cases had valid response on this variable, ranging from zero to 53 years, with around 17.5 (10.4 S.D.) as the average. In addition, I examined whether a scientist had ever held a high profile administrative position as Department Chair/Head, Dean, Director of research center or institution, or Chaired Professorship (*Academic leadership*). This is a dummy variable with 1 indicating the occurrence of the event. Around 24 percent of the scientists in this sample had ever held such kind of administrative positions.

Scientific Achievements. Czarnitzki and colleagues (2009) argued that a complete "crowding out" of scientific activities by commercialization engagement is highly unlikely for academic scientists as their career development still heavily depends on their academic reputation. In fact, research has shown a strong and positive relationship between publishing and patenting (Azoulay, et al., 2007; Breschi, Lissoni, & Fabio, 2005; Kira & Alberto, 2005; Thursby & Thursby, 2005; Whittington & Smith-Doerr, 2008). In particular, short-term publications may reflect a new discovery of prolific research area and more opportunities for patent pursuit (Azoulay et al. 2007). In addition, research grants and Ph.D. students not only signal a faculty scientist's achievement but indicate the scale of material and human resources that can be utilized for scientific and commercial endeavors. In other words, the more successful a faculty scientist is, the larger grant money and more students s/he has, and the higher probability s/he would have novel findings and more resources for patenting. Both noticeable academic

[27] It is highly correlated with physical age, rank, and tenure status, and so these other variables are not included to avoid a multicollinearity problem. In addition, its squared term was created and tested for model building, but the results remained similar after adding this term. Thus, in the final report, I do not use its squared transformation.

achievements (a large amount of publications and grants) and larger number of Ph.D. students would increase the probability of receiving invitations from industry to get involved in patenting and other commercial activities. At the same time, women are always found to lag behind men on many of the achievement measures.

Academic scientists' scientific achievements were measured through their recent publications in year 2004-2005 *(# of journal articles* and *# of conference proceedings*)[28], the scale of their research grants (*Grant amount*), and the total number of the Ph.D. students they supervised in year 2001-2005 *(# of Ph.D. students supervised*). In this sample, the mean on journal articles and conference proceedings is 3.8 (1.7 S.D.) and 2.7 (1.9 S.D.) respectively. The scale of research grants refers to the total amount of grants awarded to the research projects that an academic scientist was involved in as PI or Co-PI in year 2004-2005. This variable ranged from zero to 154 million dollars, with the average being 1.66 (6.8 S.D.) million dollars. To shrink the dispersion of this variable, natural logarithm transformation was performed before including it in regression models. I used the total number of a scientist's doctoral students graduated in the previous five years (2001-05) as a third measure of scientific achievement. In this sample, this variable has values ranging from zero to 20, with the average being 1.9 (2.5 S.D.).

Work Context. Extant research has recognized the rate of patenting varies substantially across disciplines and universities (Owen-Smith & Powell, 2001; Thursby & Thursby, 2002). To the extent that different research outcomes have different

[28] The two variables have 7 categories, with "1" indicating zero publication, "2" 1-2 publications, "3" 3-4 publications, "4" 5-6 publications, "5" 7-9 publications, "6" 10-14 publications, and "7" 15 or more publications.

probability of being patented (Azoulay, et al., 2007) and patents in different fields have distinct probabilities to be finally commercialized (Agrawal & Henderson, 2002), scientists' decision about whether to engage in patenting is likely to vary across fields. Additionally, although women are less likely to participate in the optional activity across all disciplines, their decision may be contingent to specific disciplinary context (e.g. in biology great progress has been achieved towards gender equality and so women in this field may be more willing to take the risky venture), which leads to the variation of gender pattern in patenting from one discipline to another. The empirical evidence also revealed that scientists are more likely to patent when they are employed at universities with large patent stock (Azoulay, et al., 2007). The large patent portfolios may reflect the effective delivery of incentives policies and practices as well as a well-functioning TTO.

I included four dummy variables, *Chemistry*, *Biology*, *Computer Sciences*, and *Electronic Engineering*, with Physics as a reference field, to indicate a scientist's disciplinary affiliation and account for the gender effects that may be mediated through disciplines. This sample consists of 21, 21, 20, 16, and 22 percent of scientists from chemistry, biology, computer sciences, and electronic engineering respectively. Following Azoulay et al. (2007), two variables were included to account for the university-level characteristics relevant to faculty scientists' patenting activities: 1) the establishment of a TTO in a scientist's university (*Active TTO in R's university in 2005*), and 2) the total number of new patent applications filed by a scientist's university. 80 percent of the scientists were affiliated to universities that had an active TTO in year 2005 (*The patent application stock of R's university in 2005*), and all represented universities had patent applications filed in 2005 ranged from zero to 601, with 107.5

(155.6 S.D.) being the mean. All these variables and their definitions are listed in Table 3-3.

Table 3-3 Variables and their definitions in the survey data analysis

Variables	Definition
Dependent Variable	
Patenting involvement	A dummy variable with 1 indicating a scientist filed at least one patent application during the five-year period 2006-2010. (the dependent variable in the multiple logit analysis)
Patenting productivity	An interval variable indicating the total counts of an academic scientist's patent applications in 2006-2010. (only included in bivariate analysis)
Independent Variables	
Female	A dummy variable with 1 indicating a woman scientist
Collaboration network size	A interval variable indicating the total number of collaborators an academic scientist has
Industrial ties	A dummy variable indicating whether an academic scientist has at least one collaborator in industry
Governmental ties	A dummy variable indicating whether an academic scientist has at least one collaborator in government
Inter-university ties	A dummy variable indicating whether an academic scientist has at least one collaborator in other universities
Interdisciplinary ties	A dummy variable indicating whether an academic scientist has at least one collaborator in other departments
Control Variables	
Prior Industry employment	Dummy variable indicating whether an academic scientist had full-time employment in industry before
Prior government employment	Dummy variable indicating whether an academic scientist had full-time employment in a government agency or a NPO before
Postdoctoral appointment	Dummy variable indicating whether an academic scientist had postdoctoral appointment(s) before
Joint appointment with other department(s)	Dummy variable indicating whether an academic scientist had formal joint appointment with another academic department

Table 3-3 (continued)

Lab/Center affiliation	Dummy variable indicating whether an academic scientist had membership with a permanent S&E lab or center
# of years since Ph.D.	Interval variable indicating the number of years from an academic scientist earned his/her Ph.D. to 2006
Academic leadership administrative position	Dummy variable indicating whether an academic scientist had a high-profile administrative position
# of journal articles	Ordinal variable indicating the number of journal articles that an academic scientist published in previous two years
# of conference proceedings	Ordinal variable indicating the number of conference proceedings that an academic scientist published in previous two years
Grant amount	Interval variable indicating the total amount of grants awarded to an academic scientist in the previous two years (its natural logarithm is used in multiple logit analysis)
# of Ph.D. students supervised	Interval variable indicating the number of Ph.D.s an academic scientist supervised in the previous five years
Biology	
Electronic Engineering	Dummy variables indicating an academic scientist's disciplinary affiliation with Physics as the reference group
Chemistry	
Computer Sciences	
Active TTO in R's university(2005)	Dummy variable indicating whether an academic scientist's employing university had an active TTO in 2005
The patent application stock of R's university(2005)	Interval variable indicating the number of patent applications of an academic scientist's employing university in 2005

3.3.4. Analytical Methods

The analyses in this part are critical as they test the key relationships hypothesized. I first gauged the gap between genders on patenting performance. The means of the female and male group on patenting performance measures, *Patenting Involvement* and *Patenting Productivity*, were compared. Then, I compared the means between genders on all the boundary-spanning collaboration variables, *Collaboration network size, Industrial ties, Governmental ties, Inter-university ties, and Interdisciplinary ties*.

The third step was to test the hypotheses concerning how boundary-spanning collaboration interacts with gender to affect patenting performance. Multivariable analyses were adopted at this stage. The goal here is twofold, to estimate whether boundary-spanning collaboration variables are a strong predictor of patenting involvement and whether and how the introduction of them can help explain the gender difference in patenting involvement. P*atenting involvement* was the dependent variable used in the analysis[29] and given the dichotomous nature of this dependent variable, logit regression were used for model estimation. The multivariate logit analysis allows variables to enter the equation in groups. By introducing variables in group, I could tease out the net effect of the key collaboration variables' effects and also their interaction effects with gender. The multivariate analysis design can be expressed as the following equation:

Odds of patenting involvement= *f* (female + boundary-spanning collaboration + female × boundary-spanning collaboration + boundary-spanning experiences + academic positions + scientific achievements + contextual conditions)

[29] Considering the highly skewed distribution of patenting productivity, the cases having patent application(s) during 2006-2010 in this sample are not sufficient for appropriate modeling

4. FINDINGS

As explained in the Chapter 3, I performed two sets of analyses on different sources of data, namely, large-scale patent records and individual-level data collected mainly through a national representative survey. The purpose of analyzing the population of patent outputs is to gain a basic understanding of nanotechnology, a new technology precipitously emerging in the early 21st century, especially the tendency toward collaboration and women's (relative to men's) representation in this field. The panoramic analysis is informative because knowledge about the new context would complement and enhance our comprehension of specific micro-level mechanisms relevant to the establishment and reinforcement of the gendered pattern (Ridgeway 2009). But the focus is more on knowing the group of academic scientists in nanotechnology, especially what gender distinctions on collaboration and patenting are in this group, which has to be unfolded in individual-level information. Therefore, I undertook analyses, both descriptive and explanatory, on survey data that comprise rich collaboration and background information about individual academic scientists. This chapter reports the major findings from these two sets of analyses.

4.1. A Macro-Level View of Nanotechnology

How is patenting in nanotechnology?

The patent records yielded from the selection process described in the data chapter are summarized in Appendix D. The annual growth rates were calculated[30]

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[30] Using the formula $R_i=(C_i-C_{i-1})/C_{i-1}*100\%$, where R_i denotes the growth rate for year i, C_i denotes the patent counts for year i, C_{i-1} denotes the patent counts for year before i

separately for patents in nanotechnology and those in the overall S&T area, and are demonstrated in Figure 4-1. Seen from this figure, the growth level of patents in nanotechnology was similar to the general level before 2000, indicating the production of nano-related patents did not present any noticeable difference from the general pattern.

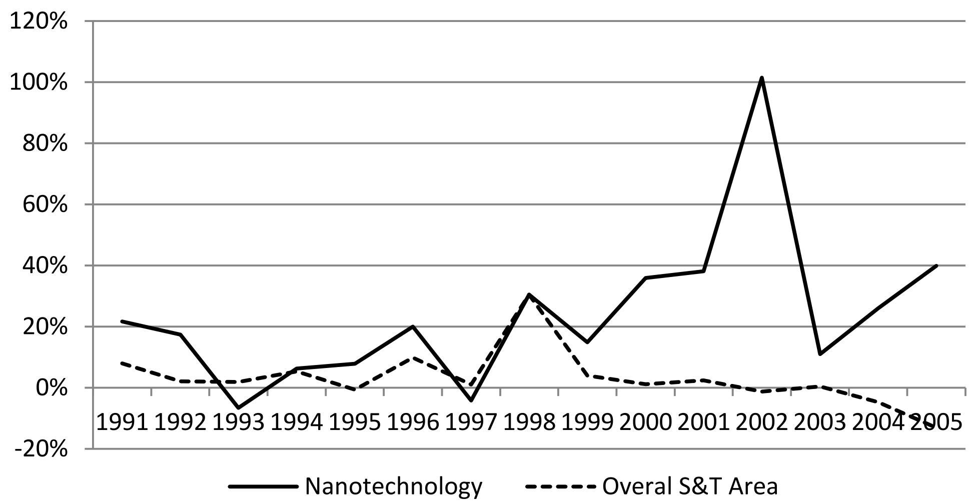


Figure 4-1 The annual growth rate, 1990-2005 (N_{nano}: 14,620; $N_{overall}$: 991,843)

However, since 2000 nanotechnology had seen distinctive increase in patents. While applying for new patents across all fields leveled off in the period 2000-03 and even decreased at an increasing rate during 2004-05, applying for nanotechnology patents increased at an impressive rate since 2000. Although the growth rate of nanotechnology patents decreased after a peak at 102 percent in 2002, it was still above 10 percent in 2003 and back to 40 percent in 2004. The divergence of nanotechnology in growth rate since 2000 is not surprising as nanotechnology has been prioritized by the U.S. government to enhance its competitiveness since early 2000s. In short, this comparison indicates that patenting activities have increased remarkably in nanotechnology whereas they have experienced a slow growth and even decrease in the general technological community since 2000.

How is collaboration in patenting nanotechnology?

I constructed two indicators, the *Average team size* and the *Share of collaborative patents,* to assess the permeability of collaborative efforts in generating ideas and producing patents at an aggregate level in nanotechnology and the overall S&T area. The average team sizes of patents in nanotechnology and the overall S&T over the 16 years are shown in Figure 4-2. On average, the size of inventor teams had become larger across all S&T fields (up from 1.8 in 1990 to 2.6 persons in 2005). The teams working on nano-related inventions and patents on average were larger than the general level and also had a tendency to increase in the short future (up from 2.0 in 1990 to 3.0 persons in 2005).

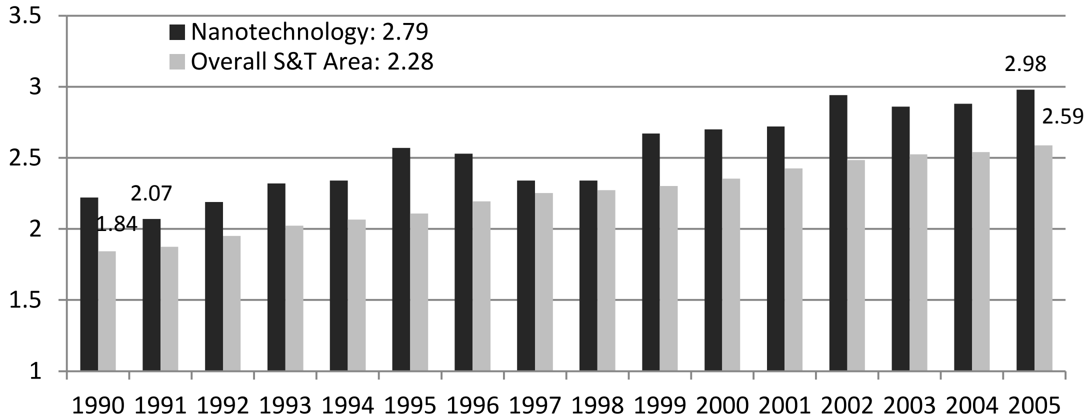


Figure 4-2 The Average Team Size, 1990-2005 (N_{nano}: 14,260; $N_{overall}$: 991,843)

As the mean of team sizes may be affected by extreme scores, the indicator the *Share of collaborative patents* directly shows the proportion of independent patents and those from collaborative efforts. Using this indicator, we can observe the growth of collaborative patents over time in a general sense and in nanotechnology. Figure 4-3 illustrates the tendency of patents being collaborative products in nanotechnology and the overall S&T area over time. Across all S&T fields, while around half patents were independent products in year 1990, only one thirds came from individual inventive work in year 2005. Although the same increasing tendency of having patents from collaborative efforts is found in nanotechnology, the proportion of collaborative patents was higher than the general level in each year of the studied time period. The results on both indicators suggest the increase of collaborative patents is a universal phenomenon but the role of collaboration in producing patents seems more prominent in nanotechnology.

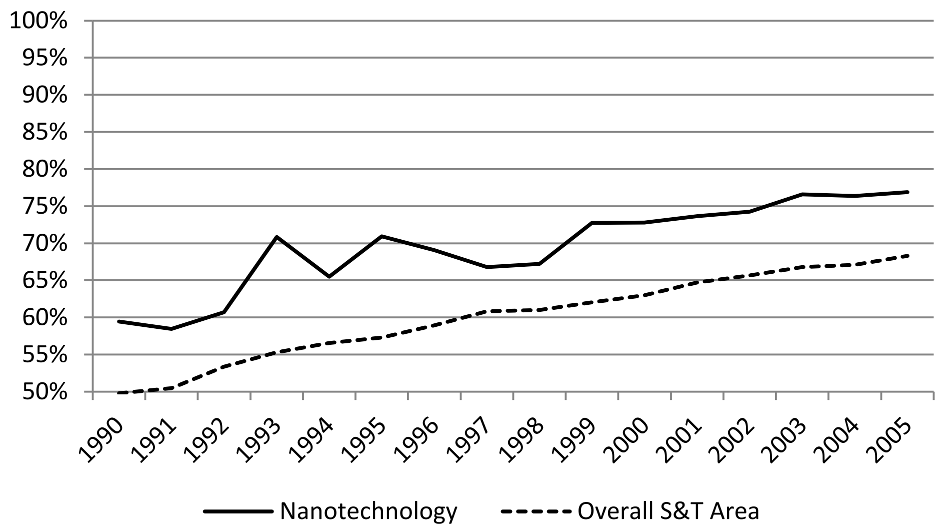


Figure 4-3 The share of collaborative patents, 1990-2005 (N_{nano}: 14,260; $N_{overall}$: 991,843)

Is nanotechnology women friendly?

With the application of the gender identification procedure, the inventors' gender information in the selected patent records was available for analysis and summarized in Table 4-1. I identified the gender of 82 percent of inventors in both nanotechnology and the overall S&T area. Among those were identified, women made up 9.7 percent of nano-inventor observations and 5.6 percent of the inventor observations in the overall S&T area. As explained in detail in the notes below Table 4-1, I can only talk about women's representation as a group because of the aggregate nature of the data used here. Lacking unambiguous information about inventor-observation relationship, unfortunately, I could not tell the exact number of female and male inventors as well as their patent records. The following gender-related analyses do not include patents without any of their inventor(s) being identified (6.5 and 0.6 percent respectively in nanotechnology and the overall S&T area). The *gender ratio* calculated for identified inventors indicates, although women were still underrepresented in nanotechnology, the gap seemed narrower in this field than the general level.

Table 4-1 The sex information of inventors* in the two patent databases

	Nanotechnology		The General Field	
Total number of inventor observations	26,710		2,262,266	
Identified female inventor observations	2505	9.4%	126,134	5.6%
Identified male inventor observations	19960	74.7%	1,726,292	76.3%
The gender ratio among identified (F:M)	1: 8.0		1: 13.7	
Non-identified	4,245	15.9%	22,306	18.1%
The number of patents whose inventors can be totally or partially identified	13,333	93.5%	985,688	99.4%
The number of patents whose inventors cannot be identified	927	6.5%	6,115	0.6%

*Note: An inventor observation refers to a distinctive first name, and thus this is an ambiguous indicator of actual inventors. First, one inventor has more than one observation in the databases due to his/her involvement in multiple patented inventions or maybe different spellings or spelling mistakes. Another possibility is that two or more different inventors share the same name. The comparisons are thus made at group level (women vs. men)

In terms of *women's relative participation*, we can observe from Figure 4-4 (the *participation* data by gender, year, and field are reported in Appendix E) that women as a group generally lagged behind men, but the situation was improving during the 16-year period in both the overall S&T area and nanotechnology. Across all S&T fields, the patents involving female scientist(s) were only 7.5 percent of those involving male scientist(s) in 1990, but it went up to 13.1 percent by the year of 2005, increasing by almost 1.75 times. Both the measure (approximately 13 percent in 1990 to 24 percent in 2005) and its increase rate (almost twice) were larger in nanotechnology, indicating that women's role in patenting nanotechnology was larger and increasing in this emerging field.

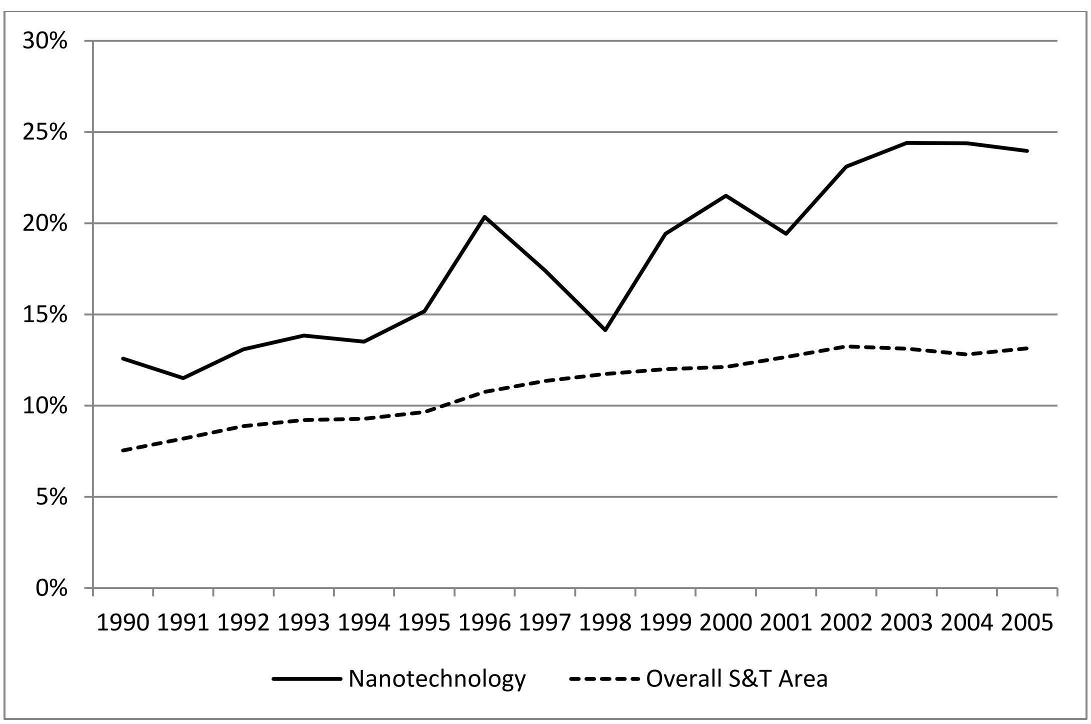


Figure 4-4 Women's Relative Participation, 1990-2005 (N_{nano}: 13,333; $N_{overall}$: 985,688)

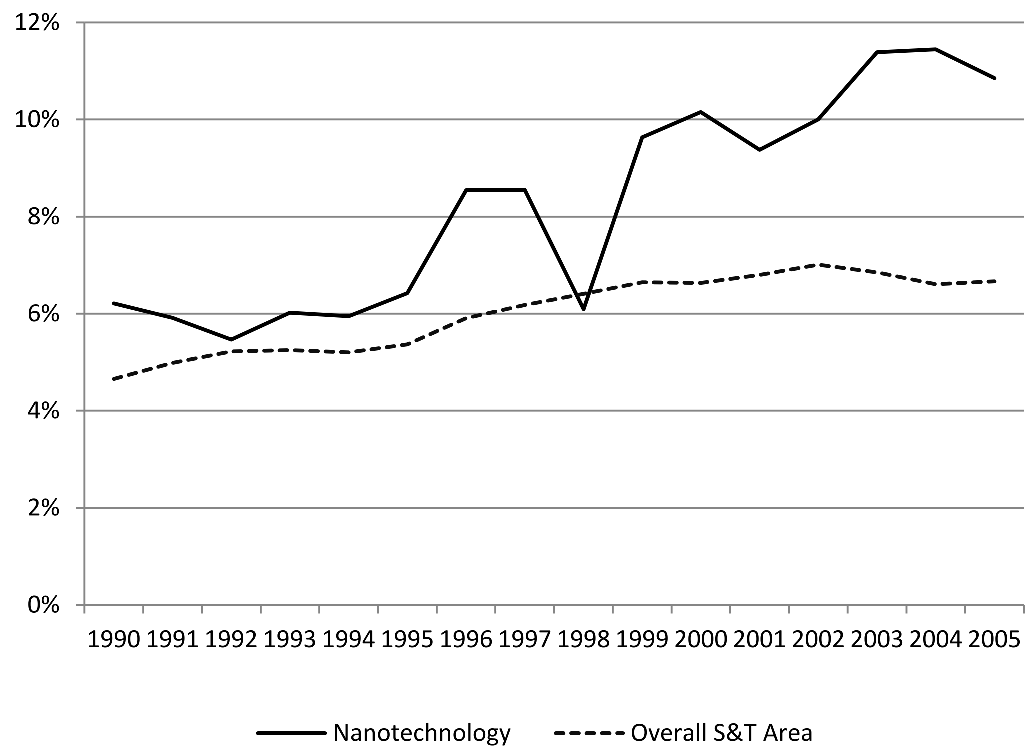


Figure 4-5 Women's Relative Contribution, 1990-2005 (N_{nano}: 13,333; $N_{overall}$: 985,688)

Based on further calculation of women's and men's *contribution* in Appendix F, *women's relative contribution* (to men's) is displayed by field and year in Figure 4-5. While women's *participation* indicates the full count of patents having at least one female inventor, women's *contribution* indicates the fractional count of patents having at least female inventor (please refer to the indicator section in Chapter 3 for detailed information about how these two indicators were constructed), suggesting the latter one is a more rigorous measure of female (relative to male) scientists' involvement in patenting. Seen from Figure 4-5, women's contribution (compared to their participation) was even smaller than men's across fields, only about 5.5-11.4 percent of men's *contribution* in nanotechnology, slightly higher than the general level (4.2-7.0 percent). The relative measure, like *women's relative participation*, also suggests the significant gender gap in patenting although it seems slightly better in nanotechnology and in more recent years.

In sum, nanotechnology seems distinct in the S&T world on the patent-based indicators. The intensive patenting activities in nanotechnology were a recent phenomenon. While it can be considered as a consequence of S&T policy's promotion and the interactions between policy and other forces (e.g. public and provide investment), it also suggests that research in nanotechnology is highly patentable and also patenting has been increasingly important in this field. The necessity and actual pervasion of collaboration in inventing and patenting nanotechnology is estimated to be above the general level. Putting together results on the three gender-related indicators, we may conceive of nanotechnology as a favorable context for women to engage in patenting. But at the same time they all speak to a gap between women and men in patenting activities.

4.2. Investigating Academic Scientists in Nanotechnology

One interesting message sent from the first set of patent analyses is that nanotechnology provides a context be more collaborative than an average level. As reviewed in the literature chapter, the intensive collaboration reflected in patent outputs may result from the actual problem-solving needs, the push from S&T policy and funding agencies, and their interactive reinforcement. Considering the collaborative context of nanotechnology, we may discern some change or resistance to change when looking specific collaboration processes at the individual level. This is what I did in the second set of analyses and this section presents important analytical results. These analyses were restrained to scientists in nanotechnology who had valid values on all selected variables (167 cases in total), but they were benchmarked against a "typical" scientist in the sample (the 1,283 cases described in Chapter 3 data section) on major characteristics including behaviors in collaboration and patenting. Throughout my report and interpretation of these results, it has to be noted that, given the small size of the sample of nanotechnology scientists, the purpose of this set of analyses (albeit quantitative) is not to make statistical generalization but shed exploratory lights on gender disparities in nanotechnology and cross-boundary collaboration as well as their interactions to shape the gender pattern in patenting.

Academic scientists in nanotechnology

The selected 167 academic scientists who conducted funded research in nanotechnology, accounting for 13 percent of the total scientists in the five disciplines. And among them, 45 percent are female, same to the share of female scientists in the sample. This comparison suggests female academic scientists had a similar (not more or less) probability to make the transition to nanotechnology as their male peers. In addition, the distribution of scientists in this group was similar to that among scientists in the sample on rank and age: 27, 29, and 44 percent of this group are assistant, associate, and full professors (compared to 27, 28, and 45 percent in the sample); the mean age is 45, with a range from 29 to 75 and S.D. 8.8 in this group (compared to the mean 47, a range from 27 to 79, and S.D. 10.1 in the sample). The distribution of scientists over age is illustrated in Appendix G.

Table 4-2 The distribution of scientists in different groups by discipline

	Biology	Chemistry	CS	EE	Physics	Total
Overall	21.4%	21.4%	19.7%	16.1%	21.3%	1,283
Nano-All	3.0%	31.1%	4.2%	26.9%	34.7%	167
Nano-Female	2.7%	25.3%	2.7%	28.0%	41.3%	75
Nano-Male	3.3%	35.9%	5.4%	26.1%	29.3%	92

Note: CS – computer sciences, EE – electronic engineering

While the distribution of scientists across disciplines was pretty balanced (around 20 percent) in the sample, scientists in the group of nanotechnology, whether female or male, were more likely coming from chemistry, electronic engineering, and physics and less likely from computer sciences and biology (see Table 4-2). The statistics have shown that women faculty in 4-year universities (including Research I and other types) accounted for around 36 percent in life sciences, 15 percent in computer sciences, 21 percent in physics, and 12 percent in engineering (NSF 2011: Table 9-24). Considering that women are even more underrepresented in engineering (including electronic engineering and chemical engineering) which seemed to constitute the major source of female nano-scientists, my estimation is the gender imbalance in terms of the number of scientists is even worse in nanotechnology.

Gender-specific patenting in nanotechnology

Table 4-3 Comparing female and male scientists on patenting performance

	Overall (N=1,283)	Nano-Female (N=75)	Nano-Male (N=92)	Nano-GD ttest
Patenting Involvement				
%	19.6	26.7	51.1	-24.4***
Patent Productivity				
Mean (including non-patenting scientists)	0.64 (2.22)	0.92 (2.83)	2.09 (3.92)	-1.17*
Mean (including only patenting	3.24 (4.08)	3.45 (4.68)	4.09 (4.69)	-0.64

Note: GD – gender difference; standard deviations are in parentheses; One-tail ttest was applied. *** p<0.01, ** p<0.05, * p<0.10.

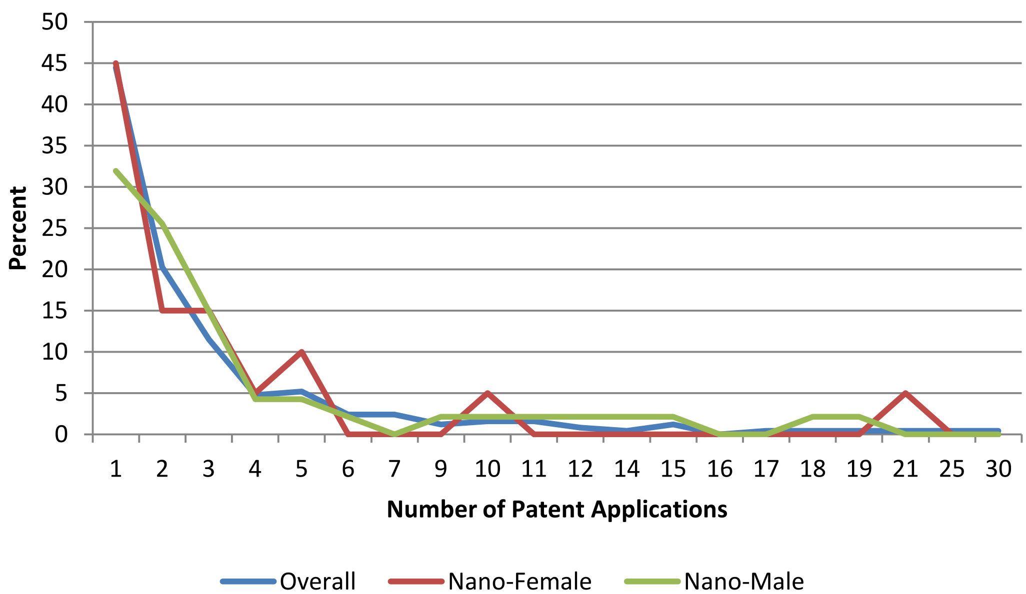


Figure 4-6 The proportion of patenting scientists by the number of patent applications

Table 4-3 and Figure 4-6 present the descriptive results of patenting involvement and productivity by gender among scientists in nanotechnology (the results from the overall sample were included for comparison purpose). Generally speaking, a gender gap is prominent, especially in terms of patenting involvement and patent productivity taking non-patenting scientists into account. However, several points emerge from more careful inspections of the results. First, on all the three measures of patenting performance, women performed worse than their male peers in nanotechnology but their average performance was still above the general level. Furthermore, the gender difference in nanotechnology primarily lied on the “involvement” stage and women’s disadvantage in patenting rate seemed negligible when only patenting scientists were focused on.

After I further broke the two gender groups in nanotechnology by discipline (see Appendix H), I found that the patenting rate among women was higher in chemistry and among men in electronic engineering. Due to the fact very few scientists came from biology and computer sciences, the patenting rates might be unreliable in these two disciplines. Additionally, the disaggregation of the small group by gender and discipline might have impacts not only on the descriptive results but the later multivariate analytical results. Therefore, cautions should be taken in any attempt to generalize these results. Finally, the figure shows the distribution on patenting productivity was generally skewed. In particular, the proportion of those who had filed more than five patents was 14, 10, and 20 percent in the overall sample, the female and male scientists in nanotechnology respectively, and the total patent applications produced by these productive scientists accounted for 50, 45, and 60 percent of total patent applications produced in each group.

However, the distribution of male scientists in nanotechnology seemed more even, and that of female scientists tends to be both skewed and scattered.

Gender patterns on boundary-spanning collaboration in nanotechnology

Table 4-4 offers rich information about collaboration behaviors of academic scientists' in the overall sample and in the two gender groups in nanotechnology. First, these scientists' collaboration network ranged from zero to 10, with the average being 5, a reasonable number suggested by previous research (Marsden 1987; McPherson, Popielarz, and Drobnic 1992; Walsh and Maloney 2002). Second, a significant majority of these academic scientists (71 percent) had collaborators in other university, suggesting inter-university collaboration has been commonplace among academicians, at least in the studied disciplines and research intensive universities. Interdisciplinary collaboration within the same university ranks the second in popularity. However, only a small share of academic scientists had built cross-sector collaborative relationships, especially academia-industry collaborations.

Table 4-4 Comparing scientists in different groups on boundary-spanning collaboration

	Overall (N=1,283)	Nano-Female (N=75)	Nano-Male (N=92)	Nano-GD
Collaboration Network Size	4.37 (2.80)	4.65 (3.17)	5.00 (3.15)	-0.35
Industrial Ties (%)	10.7	9.3	18.5	-9.2**
Governmental Ties (%)	19.5	22.7	22.8	-0.1
Inter-University Ties (%)	71.1	69.3	75	-5.7
Interdisciplinary Ties (%)	41.7	50.7	55.4	-4.7

Note: GD – gender difference; Standard deviations are in parentheses; One-tail ttest was applied, *** p<0.01, ** p<0.05, * p<0.10.

In terms of collaboration network size and the specified four kinds of boundary-spanning collaboration ties, women seemingly achieved parity with their male colleagues in nanotechnology except on the measure of collaboration with industry. While inter-university collaboration is commonplace and tends to be intra-disciplinary collaboration, female scientists, as male scientists, in nanotechnology were more likely to pursue inter-sector and interdisciplinary collaboration (again except for academia-industry collaboration) than a typical scientist in the overall sample. This observation can be considered to reflect the interdisciplinary nature of nanotechnology.

<u>The relevance of boundary-spanning collaboration to gender-specific patenting in nanotechnology</u>

To test the power of boundary-spanning collaboration in explaining the gendered pattern in patenting involvement, I regressed *Patenting involvement* against the four measures of boundary-spanning collaboration and collaboration network size as well as their interactions with gender, controlling for a series of selected variables. In this sub-section I first describe the nanotechnology scientists by gender in terms of boundary-spanning experiences, academic ranks, scientific achievements, and the conditions of contexts where they were located. Again they are compared to the "typical" scientist in the overall sample here. Then I present a correlation matrix of all variables included in the multivariate regression analysis. Finally I present the results from a few models of logit regression on *Patenting involvement*.

Table 4-5 Comparing scientists by gender in nanotechnology on selected control variables

	Overall (N=1,283)	Nano-Female (N=75)	Nano-Male (N=92)	Nano-GD
Prior industry employment	9.4%	8.0%	12.0%	-4.0%
Prior government employment	15.0%	18.7%	17.4%	1.3%
Postdoctoral appointment	68.3%	73.3%	76.1%	-2.8%
Joint appointment with another department	16.7%	21.3%	20.7%	0.6%
Lab/Center affiliation	23.9%	38.7%	37.0%	1.7%
# of Years since Ph.D.	17.5 (10.4)	15.3 (8.0)	16.4 (9.4)	-0.9
Academic leadership	24.1%	26.7%	31.5%	-4.8%
# of journal articles	3.8 (1.7)	4.5 (1.7)	4.5 (1.7)	0
# of conference proceedings	2.7 (1.9)	3.2 (2.0)	2.8 (2.0)	0.4
Grant amount ($million)	1.66 (6.80)	1.82 (3.03)	3.54 (11.10)	-1.72*
# of previous Ph.D. students	1.9 (2.5)	2.3 (2.9)	3.3 (3.7)	-1.0**
Active TTO in R's university in 2005	80.3%	88.0%	81.5%	6.5%
The patent application stock of R's university in 2005	107.5 (155.6)	111.0 (157.4)	115.9 (167.9)	-4.9

Note: GD – gender difference; Standard deviations are in parentheses; One-tail ttest was applied, *** p<0.01, ** p<0.05, * p<0.10.

Table 4-5 reports the means on all selected control variables for the female and male scientists in nanotechnology except the discipline dummy variables (the distributions on the five disciplines were discussed earlier). Overall, regardless of gender, scientists engaging in nanotechnology on average, compared to an average scientist in the overall sample, tended to have boundary-spanning experiences (except female scientists in this group are less likely to have prior industry employment), come from recent Ph.D. cohorts, possess academic leadership positions, be more productive in publishing journal articles and conference proceedings, acquire a larger amount of research grants, supervise more doctoral students, and locate in universities having active TTOs and larger stock of patent applications. This comparisons suggest a self-selection or selection effect, that is, scientists who decided to or were qualified to engage in nanotechnology were more competent according to the ordinary measures of scientific excellence (e.g. leadership positions, publication productivity, and research grants). This is understandable given the combination of nanotechnology's high level of complexity, many risks and uncertainties, but strategic role in the national scientific and economic development agenda.

When only scientists in nanotechnology are concerned, the comparison of means of the two gender groups indicates that women had slightly lower values on some variables and slightly higher on the other variables, but these differences did not reach a significant level except that they have significantly smaller amount of research grants and significantly fewer Ph.D. students. In brief, we may conclude that in nanotechnology female scientists were comparable to their male peers, which is highly likely due to the selection and self-selection effect.

Before moving to multivariate regression models, I checked the correlation matrix of all variables included in the modeling that provided the Pearson's *r* of each pair of these variables (see Table 4-6). The matrix suggests most of the variables included are correlated but only a few Pearson's *r*s have their absolute values higher than 0.40, suggesting the multicollinarity problem not be an issue for the following multivariate analyses.

Table 4-6 Correlation matrix of variables used in the logit regression analyses

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Patent involvement	1.00							
(2) Female	-0.25	1.00						
(3) Collaboration network size	0.06	-0.05	1.00					
(4) Industrial ties	0.12	-0.13	0.26*	1.00				
(5) Governmental ties	0.02	0.00	0.39*	-0.06	1.00			
(6) Inter-university ties	0.04	-0.06	0.69*	0.14	0.21*	1.00		
(7) Interdisciplinary ties	0.18*	-0.05	0.56*	-0.03	0.22*	0.34*	1.00	
(8) Prior industry employment	0.05	-0.07	0.04	0.14	-0.09	0.03	-0.04	1.00
(9) Prior government employment	-0.10	0.02	0.05	-0.10	-0.03	0.08	0.00	-0.05
(10) Postdoctoral appointment	-0.17*	-0.03	0.07	-0.12	0.05	0.08	0.18*	-0.12
(11) Joint appointment with another department	0.24*	0.01	0.12	0.12	0.04	0.05	0.07	0.02
(12) Lab/Center affiliation	0.07	0.02	0.18*	0.10	0.14	0.09	0.16*	-0.02
(13) # of Years since Ph.D.	-0.01	-0.06	0.01	0.01	0.13	-0.01	0.02	-0.17*
(14) Academic leadership	0.04	-0.05	-0.03	0.04	0.03	-0.01	-0.03	-0.13
(15) # of journal articles	0.21*	0.00	0.09	-0.12	0.09	0.04	0.02	-0.17*
(16) # of conference proceedings	0.13	0.08	0.07	0.18*	-0.05	-0.01	-0.16*	0.15*
(17) Natural logorithm of grant amount	0.12	-0.06	0.19*	0.07	0.15	0.12	0.13	0.07
(18) # of previous Ph.D. students	0.32*	-0.14	0.17*	0.14	0.08	0.07	0.12	-0.08
(19) Biology	0.07	-0.02	0.02	-0.07	-0.10	0.03	0.09	-0.06
(20) Electronic engineering	0.14	0.02	0.12	0.17*	-0.01	0.04	-0.05	0.15*
(21) Chemistry	0.03	-0.11	-0.10	-0.05	-0.06	-0.08	0.11	-0.14
(22) Computer Sciences	0.01	-0.07	-0.03	0.00	-0.04	0.00	-0.16*	0.23*
(24) Active TTO in R's university in 2005	-0.02	0.09	0.11	0.03	-0.04	0.03	0.06	-0.02
(25) The patent application stock of R's university in 2005	0.10	-0.02	0.18*	0.13	0.05	0.10	0.08	0.02

Note: *p<0.05

Table 4-6 (continued)

Variable	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) Patent involvement								
(2) Female								
(3) Collaboration network size								
(4) Industrial ties								
(5) Governmental ties								
(6) Inter-university ties								
(7) Interdisciplinary ties								
(8) Prior industry employment								
(9) Prior government employment	1.00							
(10) Postdoctoral appointment	0.13	1.00						
(11) Joint appointment with another department	0.07	-0.14	1.00					
(12) Lab/Center affiliation	-0.01	-0.06	0.24*	1.00				
(13) # of Years since Ph.D.	-0.13	0.02	0.12	0.12	1.00			
(14) Academic leadership	-0.13	-0.20*	0.25*	0.15	0.56*	1.00		
(15) # of journal articles	0.02	0.06	0.20*	0.01	0.14	0.15	1.00	
(16) # of conference proceedings	-0.12	-0.43*	0.20*	0.14	0.02	0.25*	0.17*	1.00
(17) Natural logorithm of grant amount	-0.04	0.07	0.08	-0.02	0.03	-0.06	0.11	0.06
(18) # of previous Ph.D. students	-0.05	-0.11	0.11	0.27*	0.35*	0.38*	0.42*	0.25*
(19) Biology	0.28*	0.10	0.00	0.01	-0.03	-0.04	-0.01	-0.14
(20) Electronic engineering	0.00	-0.58*	-0.01	0.00	-0.09	0.08	-0.02	0.49*
(21) Chemistry	-0.11	0.33*	-0.12	0.01	0.01	-0.15	-0.03	-0.40*
(22) Computer Sciences	-0.10	-0.22*	0.19*	0.08	0.13	0.13	-0.10	0.29*
(24) Active TTO in R's university in 2005	0.03	-0.02	0.06	0.03	-0.10	-0.09	0.11	0.03
(25) The patent application stock of R's university in 2005	0.00	0.01	0.02	0.12	0.09	0.08	0.29*	0.10

Note: *p<0.05

Table 4-6 (continued)

Variable	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
(1) Patent involvement								
(2) Female								
(3) Collaboration network size								
(4) Industrial ties								
(5) Governmental ties								
(6) Inter-university ties								
(7) Interdisciplinary ties								
(8) Prior industry employment								
(9) Prior government employment								
(10) Postdoctoral appointment								
(11) Joint appointment with another department								
(12) Lab/Center affiliation								
(13) # of Years since Ph.D.								
(14) Academic leadership								
(15) # of journal articles								
(16) # of conference proceedings								
(17) Natural logorithm of grant amount	1.00							
(18) # of previous Ph.D. students	0.11	1.00						
(19) Biology	0.03	0.03	1.00					
(20) Electronic engineering	0.10	0.12	-0.11	1.00				
(21) Chemistry	-0.03	-0.01	-0.12	-0.41*	1.00			
(22) Computer Sciences	-0.15	0.05	-0.04	-0.13	-0.14	1.00		
(24) Active TTO in R's university in 2005	0.03	0.08	0.08	0.15	-0.07	0.01	1.00	
(25) The patent application stock of R's university in 2005	-0.02	0.36*	-0.07	0.10	0.02	-0.07	0.30*	1.00

Note: *p<0.05

Table 4-7 presents the results of logit regression models for scientists in nanotechnology. Chi-square tests show that all models are significant at the 0.05 level except Model 6 which is significant at the 0.10 level. Across the first four models, the odds ratios and significant test results of *Female* suggest the gender gap remained pronounced after adding control and collaboration variables known to be predictors of patenting involvement. Model 1 indicates that women were less likely to engage in patenting than men, with their odds of doing so being about 27 percent as high as men's. The difference is significant at a 0.01 level, which is consistent with the result from comparison of means between genders on patenting involvement. Unless noted specifically, all important estimates are compared and discussed below as all other variables are held at their means.

Control variables suggested by prior research were introduced in Model 2. The estimates yielded suggest that, having joint appointment with other department(s), the amount of research grant, and the number of supervised Ph.D. students could powerfully predict patenting involvement. Considering nano-related research is application-oriented and experiment-based, it is intuitively acceptable that with a better financial standing, more advanced research design relied on expensive and sophisticated facility could be carried out for more scientific breakthroughs and patentable results. Due to its heavy dependence on experiments, research in nanotechnology needs sufficient human resources in addition to financial and material recourses. While the number of students is an indication of human resources, it is also an indication of innovative opportunities as some students working in industry may send invitations to engage their previous supervisors in commercialization related projects. In this sense, the finding about positive association between it and patenting engagement is not unexpected.

In addition, the disciplinary background is worthy noticing. It seems that scientists in biology and chemistry had higher probabilities of patenting than those in the rest of these five disciplines. The descriptive analysis found that the cases falling into biology and computer sciences were limited, which drives me to be skeptical on the reliability of the estimates for these discipline dummies. However, the inclusion of these discipline variables is important in indicating the relevance of scientists' disciplinary background. The implication could be that, in nanotechnology which is widely assumed as an interdisciplinary field, the disciplinary background counts for participation and performance improvement opportunities. Nevertheless, more extensive research should be undertaken to verify the result and provide in-depth information for its interpretation. Furthermore, being employed in government or other public agencies predicts no involvement in patenting. Considering the conflicting interests in commercialization and open sciences (see Shibayama et al 2012 and the research cited there) and the norms, attitudes, and practices towards public goods, the negative association may be understood as the result of such contradictory influences.

Finally, the results suggest that having an active TTO on campus may discourage academic scientists' involvement in patenting. Previous research (Siegel, Thursby, Thursby, & Ziedonis, 2001) suggested that the barriers exist between university and industry regarding technology transfer. If this is true, universities that make efforts to promote technology transfer might choose strategies other than facilitating academic-industry collaboration. And so one possible explanation for the strong negative relationship between the two university-level factors in nanotechnology is that, as collaboration (especially close collaboration with industry) tended to serve as an effective channel for nanotechnology scientists to be involved in patenting, the collaboration was not supported and even hindered by universities that were even more proactive in promoting technology transfer.

Moving to Model 3 and 4, I found the introduction of boundary-spanning collaboration variables and their gender-specific interactions did not change much the estimates in Model 2 for two exceptions. First, the positive effect of journal articles was revealed significant in the more specified models. This pattern is more consistent with previous research (Stuart et la. 2007) that claimed a larger number of publications in a short term might signal the achievement of some scientific breakthrough which increases the probability of following patenting activity. Also, it is in line with the argument that nanotechnology is a science-based technology and featured with a parallel pattern of scientific discovery and technological application (Mowery, 2011). I regard the revealed association between publication and patenting involvement as support for incorporating these variables for model improvement. Second, the estimate of *Female* became less significant in Model 4, suggesting the specification of boundary-spanning collaboration's effects by gender is more appropriate. Therefore I also ran Model 3 for female and male scientists in nanotechnology separately (Model 5 & 6) for a deeper understanding of whether these variables may have varying effects on patenting involvement systematically across genders. Then I focused on the estimates of the collaboration variables in Model 4, but understanding them in relation to their interactions with gender in the same model and in comparison to those in Model 3, 5, and 6.

Generally speaking, the situation is more complicated than I expected. First, not all types of boundary-spanning collaboration would strongly promote patenting involvement, although they tended to pose positive influences. Second, the effects of these variables were different for women and men, in terms of not only strength but direction. Specifically, having governmental ties and inter-university ties seemed unimportant predictors. Considering patenting is still largely optional today and there are ongoing debates about the legitimacy in the broad public research community, this finding implies the majority of these relationships were not purposively developed for commercial pursuits. It could also be, even though the collaborative relationships of the two types span different organizational and sector boundaries, the resources resided in them tended to be homogeneous and had little role in stimulating innovative activities.

While collaboration with industry was a strong predictor of patenting involvement for male scientists, having such kind of collaboration tends to predict lower involvement among females. Because only 7 cases in the female group who had industrial ties (and 1 of them had patented in the focal 5 years), I am seriously concerned about the reliability of the variable estimate in this group. Bearing this in mind, the discovered association is consistent with the "return deficit" hypothesis (discussed in the literature chapter). And it seems especially valid with the support of Ridgeway's (2009) account about the interaction between gender frame and context, that is, in a gendered context (industries involved in nano-related production here) people tend to empower gender-based stereotypes, question women's legitimate status, and adopt unfair treatments towards women (not offering important information and resources in this case). Back to the concern rooted in the small sample size, though, more verification and confirmation is needed in the future research.

Interdisciplinary collaboration was highly likely to facilitate involvement in patenting as expected. Although interdisciplinary collaboration relationships were also established in the academic environment as inter-university ones, they were more likely to be initiated and developed for actual problem-solving or other application goals according to knowledge about interdisciplinary research (Rhoten and Pirman 2007; Jacob and Frickel 2009), and thus more likely to motivate the exchange and integration of different resources (especially intellectual resources) for patentable results. More interestingly, while the effect remained positive when separating the sample into women and men, it became even stronger among women but did not reach significance among men. As for the variation, Ridgeway's (2009) theory can again be cited as a convincing explanation. More specifically, as the context (academia here) is less gendered, women may face modest gender biases, receive more equal treatment as coworkers in information and resource sharing, and consequently benefit more than men from critical collaboration to realize the larger marginal returns.

Finally, the estimates for collaboration network size were negative across the last four models (Model 3-6), and my interpretation is that a larger size of collaboration network did not necessarily increase the chances of receiving needed resources as previous research argued (Borgatti, et al., 1998; Burt, 1983), at least with regard to patenting engagement. Once the types of collaborative relationships offering more direct indication of network diversity were controlled, a larger collaboration network might hint more costs in managing and maintaining such a network or more influence from peers against commercialization (the correlation between this measure and the collaboration within department, the collaboration with other universities are very high, 0.67 and 0.69 respectively).

To summarize, during the course of presenting and interpreting the analytical results in this section, I provided a detailed description of scientists engaging in nanotechnology. Compared to a typical scientist in the general S&T area, an "average" scientist in this group was not different in terms of age and rank, but tended to come from more recent Ph.D. cohort, be more successful on various scientific achievement measures, and not be affiliated with biology or computer sciences. In terms of the gender contrast within nanotechnology, women tended to be minority in nanotechnology but comparable to men on most standing and achievement indicators (except the amount of research grants and the number of supervised doctoral students). My conclusion about the gender composition in the new field is based on the result in this study (women had a similar rate of making the transition as men) and the current composition in the major disciplines that constitute nanotechnology (physics, electronic engineering, and chemistry). Recall this sample of nanotechnology scientists is very small and biased toward research intensive university faculty, and so the identified distinctions of nanotechnology scientists and the gender pattern in this group should be read with cautions about their limitation in generalization.

Additionally and more importantly, I tested all hypotheses in this set of analyses. Let me revisit these hypotheses here. First, H1 has been empirically evident in the comparisons of means on patenting involvement and productivity as well as results from the logit regression models. A gender gap favoring men is found to mainly lie at the involvement level, and this gap remained significant even controlling for a series of variables relevant to patenting involvement, including the boundary-spanning collaboration variables of particular interest. Second, the descriptive analyses of collaboration pattern by gender in nanotechnology suggest a small gender difference in the focal group on this regard (except for industrial ties), providing some support for H2. However, the similarity or parity was likely to result from selection or self-selection rather than from this new field being women-friendly and creating more collaboration opportunities for women.

Furthermore, based on a theoretical understanding of the results (the estimates of industrial ties and interdisciplinary ties for women and men), the competing hypotheses in H3 seem both acceptable. Therefore, the two hypotheses can be combined by specifying different kinds of collaborative relationships and taking into account the contexts where the relationships take place: women benefit less from critical relationships than men if the relationships take place in a more gendered context, but benefit more if the context is less gendered. The reduced significance in Model 4 and the revealed association between journal article publication productivity and patenting involvement after specifying these collaboration-related variables (Model 3-6) suggest the necessity of including boundary-spanning collaboration variables in explaining gender-specific patenting. Again, due to the small size of the studied group, all these novel findings should be read carefully as worthy directions for further exploration rather than concrete assertions.

Table 4-7 Logit models predicting Patenting Involvement (t-Stats are in parentheses)

	Nano-All				Nano-Female	Nano-Male
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Prior Industry employment		0.823 (-0.20)	0.606 (-0.57)	0.604 (-0.57)	5.215 (1.26)	0.508 (-0.59)
Prior government employment		0.173** (-1.99)	0.205* (-1.72)	0.205* (-1.67)	1.332 (0.20)	0.166 (-1.61)
Postdoctoral appointment		0.333 (-1.42)	0.352 (-1.24)	0.327 (-1.23)	3.845 (0.95)	0.266 (-1.27)
Joint appointment with other department(s)		12.029*** (2.76)	11.473*** (2.60)	12.203*** (2.64)	7.402* (1.67)	14.913** (2.21)
Lab/Center affiliation		0.952 (-0.09)	0.861 (-0.25)	0.848 (-0.26)	0.692 (-0.41)	0.936 (-0.09)
# of years since Ph.D.		0.965 (-1.09)	0.969 (-0.90)	0.965 (-0.99)	0.850** (-2.04)	0.972 (-0.67)
Academic leadership administrative position		0.316 (-1.37)	0.277 (-1.21)	0.265 (-1.23)	0.240 (-1.10)	0.197 (-1.12)
# of journal articles		1.182 (1.02)	1.389* (1.89)	1.429* (1.93)	1.535* (1.86)	1.487* (1.81)
# of conference proceedings		0.932 (-0.35)	0.898 (-0.46)	0.873 (-0.52)	0.996 (-0.01)	0.864 (-0.48)
Grant amount		1.107** (1.98)	1.126** (1.97)	1.135* (1.96)	0.860 (-1.04)	1.173** (2.17)
# of Ph.D. students supervised		1.354*** (3.50)	1.359*** (2.91)	1.378*** (2.80)	1.530 (1.54)	1.380** (2.26)
Biology		42.015*** (3.45)	48.853*** (3.48)	40.943*** (3.13)	- [a]	- [b]
Electronic Engineering		4.758 (1.40)	7.464 (1.55)	8.037 (1.49)	4.542 (0.95)	11.106 (1.44)
Chemistry		3.268** (1.97)	3.384** (2.00)	3.444** (1.99)	1.513 (0.42)	4.640** (2.08)

Computer Sciences		0.963 (-0.03)	3.104 (0.86)	3.993 (0.99)	40.460 (1.58)	4.865 (0.95)

Note: ***p<0.01, **p<0.05, *p<0.10.

Table 4-8 (Continued)

Active TTO in R's university(2005)		0.251** (-2.08)	0.172** (-2.44)	0.171** (-2.37)	0.438 (-0.60)	0.129** (-2.18)
The patent application stock of R's university(2005)		0.999 (-0.95)	0.999 (-0.91)	0.999 (-0.90)	1.003 (1.07)	0.998 (-1.02)
Female	0.271*** (-3.71)	0.217** (-2.48)	0.238** (-2.21)	0.100* (-1.70)		
Collaboration network size			0.731** (-2.11)	0.729* (-1.93)	0.579** (-2.09)	0.710* (-1.85)
Industrial ties			6.674** (2.19)	8.549** (2.28)	0.038 (-1.48)	10.230** (2.17)
Governmental ties			1.395 (0.50)	1.565 (0.59)	0.902 (-0.08)	1.571 (0.54)
Inter-university ties			2.133 (1.01)	1.895 (0.76)	2.569 (0.78)	1.876 (0.68)
Interdisciplinary ties			3.627* (1.87)	3.163 (1.54)	71.894** (2.46)	3.363 (1.42)
Female* Collaboration network size				0.960 (-0.16)		
Female* Industrial ties				0.036 (-1.42)		
Female* Governmental ties				0.366 (-0.77)		
Female* Inter-university ties				2.027 (0.46)		
Female* Interdisciplinary				5.822		

ties				(1.19)		
Constant	1.199 (0.82)	0.534 (-0.48)	0.215 (-1.19)	0.220 (-1.15)	0.132 (0.323)	0.150 (-1.24)
Pseudo R2	0.02	0.34	0.39	0.40	0.42	0.41
Observations	167	167	167	167	73	89

Note: ***p<0.01, **p<0.05, *p<0.10.

5. CONCLUSION, DISCUSSION, AND POLICY IMPLICATIONS

5.1.Conclusion: Evaluating the Contributions in Relation to Prior Research

The rapid increase of cross-boundary interaction and collaboration as well as academic scientists' involvement in various commercial activities suggests the arrival of entrepreneurial regime (Hong & Walsh, 2009; Powell & Owen-Smith, 1998; Slaughter & Leslie, 1997; Slaughter & Rhoades, 1996; Whittington, Forthcoming; Whittington & Smith-Doerr, 2005). As the concerns have risen regarding the impacts of this trend on the opportunity structure and performance evaluation and consequently on the existing gender stratification in academia, efforts have been undertaken to investigate how and why female and male scientists differ in entrepreneurial activities. As what has been proposed in the general work on gender and science (Sonnert and Holton 1995; Smith-Doerr 2010), Rosser (2009) suggested the issue in the new context can be examined from several feminist perspectives.

Assuming that women and men are similar in capabilities and goals, a liberal feminist perspective stresses it is the structural barriers in the social system that keep women from exerting their talents and accomplishing their goals. A majority of the extant research on gender and patenting, taking this perspective, attempted to identify the major obstacles accounting for women's disadvantages. Sharing the concern that women's situation may be worsen in the entrepreneurial regime, and adopting the liberal feminist perspective, this study focuses on collaboration as the potential social mechanism hindering women's participation in patenting but theoretically enquires and empirically tests whether this mechanism would have a changing role in differentiating women's resource acquirement and patenting engagement from men's. Because this study is cutting across several research subareas, including social studies of nanotechnology, social network research, and gender studies of science in general and academic entrepreneurship in particular, it produces new knowledge, both practical and theoretical, for these subareas.

First, it joins the debates on whether nanotechnology is interdisciplinary (see the review in Huang et al 2010) from the lens of individual-level collaboration. Differing from many studies of collaboration in nanotechnology that focused on interdisciplinary, inter-institutional, and international collaboration for the impacts on technological development (Heinze & Kuhlmann, 2008; Meyer & Persson, 1998; Schummer, 2004), the current study places more attention to inter-personal collaboration for the impacts on individual scientists. The analyses of sheer patent records reveal that, while collaboration has been a general trend in S&T community, the probability of patents in nanotechnology being collaborative results is higher than an average level in the overall S&T area, and both the average inventor team size and the proportion of teamwork have been increasing in this field. The analyses of individual-level survey data, albeit requiring further confirmation, discover that both female and male scientists in nanotechnology, tend to have a higher level of boundary-spanning collaborative activities (except women on the measure of industrial ties), and the collaborative involvement seems relevant to engaging this group of scientists in patenting their research. Then, a more general implication of these results may be that innovations in nanotechnology depend more on scientists' collaboration, especially boundary-spanning collaboration. These results can be considered as supporting evidence for the interdisciplinarity of nanotechnology.

Knowing more about scientists in nanotechnology is another contribution. Until the dissertation was finished, the statistics or systematical information about scientists working in nanotechnology were not available in any government data sources, NNI official reports, or empirical studies, letting alone the understanding about gender contrast among these scientists. This study, based on estimates from a national representative sample of academic scientists in research-intensive universities in the U.S., offers some exploratory (given the small size of the focal group) but systematical basic information. One major finding is that women have similar probability of engaging in nanotechnology as men; but, as disciplinary background holds as a threshold for participating in nano-related research (physics and electronic engineering) and women have much smaller shares in these disciplines, the gender composition in nanotechnology tends to favor men, at least in research-intensive universities.

In addition, the rate of patenting and the average number of patents are higher among scientists in nanotechnology, echoing the claim that patenting activities have been intensive among academic scientists in nanotechnology (Mowery 2011) and patenting engagement tends to be included in a portfolio of performance evaluation for these scientists (Jacobs & Frickel 2009). Furthermore, as a more equal gender pattern in nanotechnology is observed from the full patent output data, both sets of analyses evidence the existence of a significant gender gap in patenting nanotechnology, especially at the involvement level. The implication is that nanotechnology presents a changing context for women's commercial participation as an emerging and interdisciplinary field (Rhoten and Pfirman 2007; Corley and Gaughan 2005), but it is not immune from the robust and prevail gendered culture in science. On the other hand, my analytical results suggest that women's more equal situation in nanotechnology is likely to result from selection and self-selection, which raises the question about how such a situation can sustain, especially considering that women may constitute only a very small proportion in the new field.

The major conceptual contributions of this study lie in extending the research on relationships of gender, collaboration (network), and scientific productivity. As reviewed in the literature chapter, the findings about gender and collaboration as well as collaboration's mediating role in gendered productivity are inconsistent. Drawing upon social capital theory that maintains structural and resource benefits in social networks featured with diversity, I develop the concept *boundary-spanning collaboration* to capture the key feature that is conducive to patenting involvement. Then I operationalize this concept as five variables that indicate an academic scientist's total number of collaboration ties and the presence of industrial ties, governmental ties, inter-university ties, and interdisciplinary ties in his/her collaboration network, and test their relationships with patenting involvement. The empirical examination provides new information to modify the current knowledge about collaboration, network, and instrumental outcomes.

As network size is usually considered as a proxy of social capital in diversity, i.e. the larger network, the more chances to access diverse resources, the more social capital, and the more successful in achieving goals (Borgatti, et al., 1998; Bozeman & Gaughan, Forthcoming; Burt, 1983), this study shows that size is negatively related to patenting involvement while specifying the various types of boundary-spanning ties. This particular finding underscores the cost side of collaboration/networking and the importance of using direct measures of network diversity in studying the association between collaboration/networking and outcomes. Besides, this study generates some general guidelines for operationalizing the concept *diversity*. To what extent a sort of relationships reflects the benefits of diversity are not determined only along one dimension. I identify four kinds of relationships in this study on the basis of institutional affiliation of collaborators (different from the ego scientist's university and department). Although defined to contain the diversity feature in the same way, they exhibit different associations with the studied outcome, patenting involvement. A deeper reflection of these ties leads to a possible interpretation that industrial ties and interdisciplinary ties contain information, resources, and attitudes that facilitate patenting involvement and at the same time are inaccessible elsewhere for academic scientists. Therefore the operationalization should be a multi-dimensional decision and targeting a specific outcome.

As gender is added to the more clarified association between collaboration and patenting, this study proves that Ridgeway's (1997, 2007, 2009) theory of gender frame is a powerful conceptual tool for the development of explanations for gender stratification in science. According to her, a few cultural categories serve as the primary frames for our daily interaction with others. In a long history of development, people in different categorized groups have both competed and coordinated, and then some beliefs emerged with acceptance from all groups of a category (e.g. class, race, and gender) about the general description of people in different groups and the ordering of the groups to power. To maintain the power and authority, the privileged group tends to reinforce these beliefs rather than change them. Gender is one of the few primary frame, which provides a fundamental guidance for the comprehension of gender differences, and especially in areas connecting to power, at all levels in our society. For instance, science is powerful in influencing national leadership and development at the profession level, scientific productivity is critical to professional success at the outcome level, and interaction, collaboration, and various processes of direct resource allocation (e.g. financial support) are crucial to higher level of productivity at the input level. It is then easy to understand the persistent and prevailing gender gap in scientific productivity (even in emerging field like nanotechnology and in terms of new measure of productivity like patenting) and in a few outcome relevant mechanisms such as collaboration.

While scholars (Lin 2001; Burt 1998; Ding et al 2006) proposed two seemingly competing hypotheses about collaboration/network returns to women relative to men, with the help of Ridgeway's (2009) theory, I modify the logic about gendered returns from collaboration/network by taking into consideration the context in which a focal relationship takes place, and use the modified logic to interpret the seemingly contradictory findings from empirical data. **The new theory is: women benefit less from critical relationships than men if the relationships take place in a more gendered context, but benefit more if the focal relationships take place in a less gendered context**. In this sense, this study not only develops the theory about network returns by gender, but adds empirical evidence to Ridgeway's theory (Ridgeway 2009).

The methodological merits of the research should be highlighted as well. First, it adopts two analytical approaches that have been used separately in previous research. The combinative approach minimizes the biases embedded in each approach and provides both a panoramic view of nanotechnology's distinctions and social dynamics at a detailed individual level from which a more comprehensive understanding of nanotechnology as a context for the interrelationship of gender, collaboration, and patenting can be drawn. Second, it extends the first name database for inventor's gender identification by adding Asian originated first names. Given the relative large and increasing proportion of Asian born or Asian originated scientists in the U.S. innovation system (Kerr, 2007), the extension improves the method for large-scale patent data analysis and makes the results more representative of inventors with different backgrounds. It also develops several patent data indicators that allow for complicated comparisons between genders and fields. Both developments increase the proportion of analyzable patents compared to previous research (Meng and Shapira 2010). In the set of survey data analyses, I deliberately differentiate the time frame for patent application data (the effect) and the collaboration network data (the cause), trying to avoid the endogeneity problem and establish a causal relationship between collaboration and patenting.

5.2. Discussion: Limitations and Future Research

Restrained with time and resources, this study has several limitations that deserve special attention when reading, interpreting, and using the results and should be addressed in future research. First, the population of patent records could have been further explored. Although the first-name identification method allows for gender-disaggregation, the inventors assigned to a gender group have to be treated aggregately. Without accurate invention-observation information, the differentiation and calculation of patents based on producing sources (industry, academia, different levels of government, specific organizations, and collaborative efforts) becomes impossible. This is especially true for patents resulted from academia-industry collaboration because of additional difficulties in identifying a substantial share of patents published/awarded through private companies but including faculty members in the list of inventors (Thursby et al 2009; Thursby & Thursby 2011). Fortunately, a recent study (Ejermo & Jung 2012) has taken the venture to combine patent records and population register data for fuller use of the patent data. This new approach should be considered for future gender-related investigations using patent data. Secondly, patent applications and grants should be differentiated as the first category reflects more individual scientists' activities while the latter more market selective results (Frietsch et al 2009). Also, because the patent data used for the individual-level data analysis were patent applications, more direct comparisons could have been made between the results from the two levels of analyses if they both were on patent applications.

In the part of survey data analyses, the sample of scientists in nanotechnology is very small, which is expected to unfavorably affect the estimates in the hypothesis-testing regression models and the generalizability of derived patterns. There are several things to do in the future to address the issue. The fundamental and impelling need is to define nanotechnology unambiguously so that data collection agencies can have a clearer idea about the boundary and the population for sample drawing. With a clear definition being given, it is possible to accurately identify scientists who make the transition to the new field and track their career development, which is sorely absent for now. More importantly, researchers can purposively design research based on the definition for data collection and analysis and then make meaningful inferences, which is an embedded limitation of the current study. Furthermore, for studies concerning gender, patenting (or other entrepreneurial activities) and nanotechnology (or other emerging fields), scientists in all kinds of higher education institutions and on non-tenure tracked positions should be included. Because prior research suggests that women are overrepresented among junior researchers and in less prestigious universities and lower ranks (Long and Fox 1995), female and junior researchers tend to engage in emerging and interdisciplinary (Rhoten and Parker 2004; Rhoten and Pfirman 2007; Corley and Gaughan 2005), and patents from higher education institutions other than Research-I universities and non-tenure tracked scientists account for a sizable share of total academic patents (Azoulay et al. 2007), the inclusion of individuals representative of all groups in higher education setting may reveal different patterns. Whether similar or different, the more inclusive approach is important to help justify and generalize the results obtained here. Thirdly, as the newly developed theory could be considered in a more general sense, that is, the collaboration/network returns are contingent on an instrumental goal by gender, it is important to use different scientist groups (e.g. life scientists) and different outcomes (e.g. publication productivity) to testify the conclusions temporarily reached here.

In the use of survey data, although the deliberate differentiation of the time for scientists' patent data and their collaborative activities is a novel strategy, the time frame (5 years) for patent application data collection is short, resulting in a limited number of cases that have patent applications and therefore little variation on the number of patent applications. Also, the short time window makes it hard to sort out motivations from the effects of collaboration for all the cases. In other words, it is possible that building collaborative relationships is motivated by patenting, and in this case the collaboration pattern is affected by, rather than affect, patenting involvement. A longer time period and a lag analysis design (one-year lag of patent applications behind the collaboration structure) should be more capable to determine the key relationships.

Aside addressing these limitations, future research has opportunities to make more improvements. As mentioned at the beginning of this chapter, the present study takes a liberal feminist perspective, assuming that women are similar to men on most aspects relevant to performance and trying to discern the barriers blocking women from patenting for final removal of these barriers. However, considerable research has pointed to the differences between women and men, especially on topic selection and the emphasis on quality (Sonnert and Holton 1995; Ding et al 2006; Symonds et al. 2006; Meng and Shapira 2010; Whittington and Smith-Doerr 2005; Long 1992; Penas and Willett 2006; Schiebinger 2008). And if the quality is the focus (e.g. citations, journal impact factor, or originality), the research found the gender difference disappears or a gap emerges favoring women. As such, a radical feminist perspective is helpful to comprehend why women are different from men on these aspects, reevaluate women's contributions, and develop a more complicated indicator system for performance evaluation to assure women have equal opportunities for professional advancement.

Plus, qualitative methods (e.g. interview and observation) should be undertaken to better understand the temporary conclusions and answer key questions arising in this study. For instance, what are the motivations behind the transition to nanotechnology? Does disciplinary background really matter? What are the motivations behind initiating collaboration across boundaries (especially with industry and scientists in other disciplines)? Are these collaborative relationships motivated by patent pursuit? What actual benefits do academic scientists obtain from different external and internal collaborations? What are the determining factors for scientists' decision to engage in patenting? How the responses to these questions vary across genders?

5.3. Policy Implications: Calling for Understanding and Change

The diversity of the scientific workplace has been recognized as a critical source for the generation of new ideas, formulation of new problems, development of new methods, and establishment of new experiments (Long & Fox, 1995; Rosser, 2009; Schiebinger, 2008; Sonnert & Holton, 1995a, 1995b). However, regardless of growing attention and efforts, women's representation and situations has not been increased much among scientists, especially in the setting of industry and federal government. This study reveals a foundation, the gendered culture, for the general issue of gender inequality and inequity in science. Without a profound cultural change, equal opportunities will never be available for women, whether in science or other professions, whether in cutting-edge or traditional scientific activities, whether in collaboration or other resource allocation mechanisms.

On the other hand, the changing culture in academia, as suggested in this study, is likely due to a large number of programs and policy interventions having been put in place to track and address the gender inequality in employment, promotion, and other aspects of career development (one example is NSF ADVANCE program), and tends to release creativity of female scientists who are traditionally excluded in science. Additionally, it is also suggested that changing culture in one subarea in science (e.g. academia) is far less than sufficient although it may have diffusing effects as different subareas (e.g. academia and industry) have been linked by many processes (e.g.

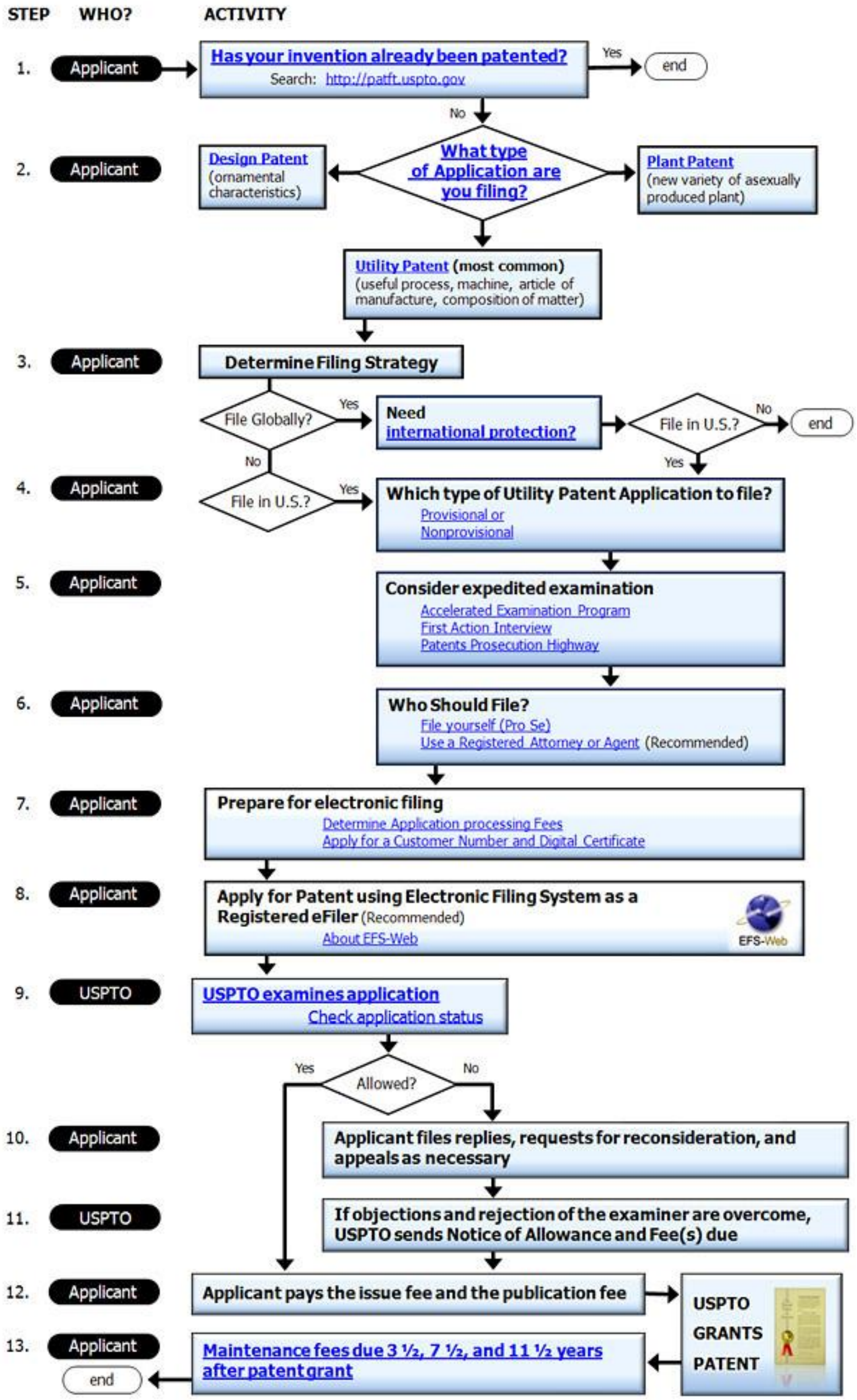
collaboration). Instead, an overarching and profound change is needed to erase those gender stereotypes favoring men and establish an individual- and merit-based system.

There are many ways to make the change, but I would suggest providing substantial support for gender studies of science to collect, track, analyze, and publicize gender-specific data at every corner in science. The lack of gender-specific information about scientists engaging in patenting and nanotechnology implies much work needs to be done in the near future. In addition to urging data collection and research conduction, publicizing (more than publishing) the raw data, aggregate statistics, and sophisticated analytical results together with their interpretations in the societal scope is important.

This study also contains implications on how to guide the academic patenting (and other forms of academic entrepreneurship) and nanotechnology (and other emerging interdisciplinary fields). The literature review and the discussion about data problem in the present research indicate that our knowledge about women's (relative to men's) participation and performance in these cutting-edge areas remains poor. This is especially so considering many general questions are still seeking for answers such as how to assess performance (the use of quantitative vs. qualitative criteria) and whether entrepreneurial activities should be encouraged in academia (Melo-Martín, 2012). In this sense, specific policy recommendations may not be given at this point as to whether and how to promote women's participation in patenting (and other entrepreneurial activities) or nanotechnology (and other emerging interdisciplinary fields). Putting this in another way, there is a direct implication for the policymaking community: encouraging and supporting more gender studies of science with diverse subjects, perspective, and methodologies to generate and accumulate knowledge about scientists' attitudes, perceptions, and actual behaviors in these new areas; and as Smith-Dorre (2010) has called, giving serious consideration to this particular stream of knowledge by incorporating it in a integrative framework for policy development from the very beginning.

Finally, although the research mainly deals with female academic scientists, the results have meaningful implications for policy design targeting the inclusion and improvement of female scientists in all employment sectors. This is so because female scientists in different settings share major characteristics and the job mobility, exchange, collaboration, and other forms of interactions have been commonplace nowadays. Pertaining to the issue of inequity and diversity, these results also provide implications for the inclusion of other underrepresentative groups (in terms of race, ethnicity, and economic background) in science.

APPENDIX A: The Flow Chart Illustrating the Process of Patent Application



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APPENDIX B: One Example of QLS Command

```
SET PAGESIZE 50000
SET LINESIZE 170

ALTER SESSION SET current_schema=patstat09s;

SPOOL 'P:\Patstat_Dissertation\General_90_05\total_counts_1.dow';


SELECT
	COUNT(DISTINCT p.publn_nr) as count,
	to_char(p.publn_date, 'yyyy'),
	a.ipc_cnt,
	a.invt_cnt
FROM
	tls201_prior a
	JOIN tls211_pat_publn p ON a.appln_id=p.appln_id
	JOIN tls207_applt_appln ap ON a.appln_id=ap.appln_id
	 JOIN tls206_person ps ON ap.person_id=ps.person_id
WHERE
	a.appln_auth='US'
	AND ps.person_ctry_code='US'
	AND p.publn_kind='A'
	AND to_char(p.publn_date, 'yyyy') between 1990 and 2000
GROUP BY
	to_char(p.publn_date, 'yyyy'),
	a.ipc_cnt,
	a.invt_cnt
;

SPOOL OFF;
```

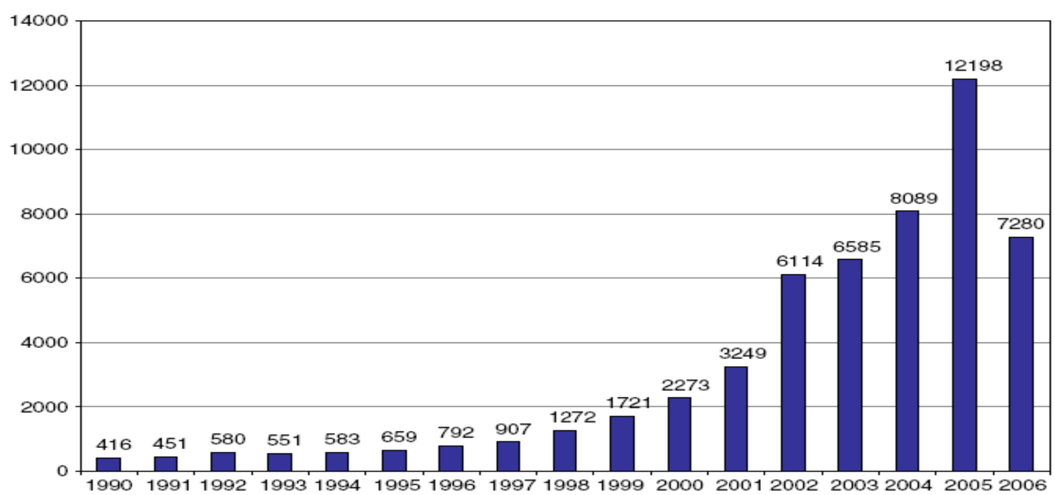
APPENDIX C: The Major Steps in Creating Georgia Tech Global Nanotechnology Patent Database

Phase I: Decide the key search terms and download patent data using these terms

- Create a pilot "field scope"
  - Drawing upon and combining search terms and insights from prior efforts to define nanotechnology search terms, espcially Kostoff et al. (2006), the CREA search, Alencar et al. (2007), ETC (2003) and Zitt and Bassecoulard (2006)
  - Ask 45 nanotechnology experts to review the pilot field scope
  - Add or remove search terms based on the responses from 19 nanoscientists (13 academics and 6 experts in industry or government)
- Base search
  - The patent data sources to be searched included MicroPatent database, US Patent and Trademark Office (USPTO), European Patent Office (EPO), Japanese Patent Office (JPO), World Intellectual Property Office (WIPO), patent offices of Germany, Great Britain, and France, and the EPO's raw data resources (INPADOC)
  - The expressions nano*, bionano*, or bio-nano* and several other of those nano search terms were used to search through patent titles, abstracts, and claims in above sources
  - A MicroPatent function was applied to the results to just one record per patent family (because a patent family includes variations of the same invention being filed with multiple patent authorities)

Phase II: Exclusion

In this phase, certain retrieved patent records were excluded based on the presence or absence of particular terms. Consequently, very few patent records were affected by the exclusion process. The final international nanopatent file contains 53,720 patent abstracts, and the following figure presents their distribution over time.



Source: Porter, Youtie, Shapira, & Schoeneck (2008)

APPENDIX D: A summary of the selected U.S. domestic patent records, 1990-2005

Publication year	Nanotechnology	The overall S&T area
1990	180	42,793
1991	219	46,195
1992	257	47,169
1993	240	48,077
1994	255	50,647
1995	275	50,268
1996	330	55,173
1997	316	55,737
1998	412	72,654
1999	473	75,576
2000	643	76,420
2001	888	78,241
2002	1,789	77,226
2003	1,986	77,523
2004	2,500	73,913
2005	3,497	64,231
Total	14,260	991,843

APPENDIX E: Women's and Men's Participation, 1990-2005

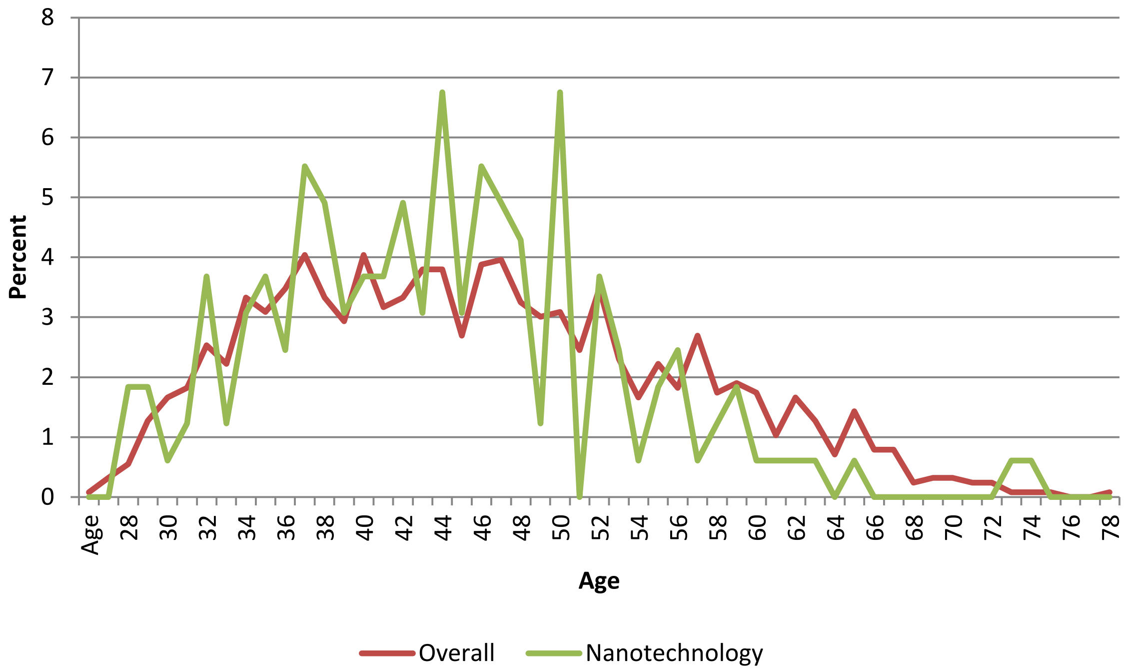
	Nanotechnology			The Overall S&T Area		
Year	Female	Male	Total	Female	Male	Total
1990	21	167	171	3129	41474	42553
1991	23	200	202	3665	44708	45921
1992	31	237	239	4050	45673	46867
1993	31	224	225	4292	46601	47848
1994	32	237	239	4564	49183	50392
1995	39	257	262	4706	48776	50002
1996	60	295	301	5733	53354	54846
1997	50	287	293	6118	53897	55442
1998	54	382	391	8224	70133	72207
1999	86	443	454	8734	72841	75103
2000	126	586	604	8931	73673	75959
2001	155	798	821	9547	75386	77719
2002	378	1636	1684	9847	74345	76694
2003	441	1807	1859	9798	74700	76973
2004	551	2260	2327	9133	71319	73389
2005	756	3156	3261	8146	61989	63773
Overall	2834	12972	13333	108617	958052	985688

Note: Because a patent team may include both female and male inventors and may be counted once for women's participation and once for men's participation in this case, it is possible the sum of women's and men's participation in a given year exceeds the total number of patents in that year.

APPENDIX F: Women and Men's Contribution, 1990-2005

	Nanotechnology			The Overall S&T Area		
Year	Female	Male	Relative ratio	Female	Male	Relative ratio
1990	9.50	152.78	0.062	1733.21	37233.38	0.047
1991	10.65	180.02	0.059	1992.00	39943.38	0.050
1992	11.31	206.81	0.055	2108.15	40386.80	0.052
1993	11.78	195.76	0.060	2152.33	41013.78	0.052
1994	12.35	207.45	0.060	2240.57	43079.36	0.052
1995	14.32	223.03	0.064	2284.37	42566.26	0.054
1996	21.40	250.36	0.085	2722.75	46086.30	0.059
1997	21.18	247.66	0.086	2852.59	46177.69	0.062
1998	20.56	337.50	0.061	3840.35	59893.41	0.064
1999	34.78	361.18	0.096	4104.83	61769.74	0.066
2000	49.50	487.60	0.102	4122.77	62171.73	0.066
2001	62.02	661.26	0.094	4279.61	62927.47	0.068
2002	134.72	1346.87	0.100	4315.39	61559.30	0.070
2003	166.48	1461.85	0.114	4220.09	61597.49	0.069
2004	207.82	1815.53	0.114	3872.43	58602.61	0.066
2005	271.52	2502.31	0.109	3376.11	50627.75	0.067
Overall	1059.88	10637.96	0.100	50217.54	815636.50	0.062

APPENDIX G: The Distribution of Scientists in Nanotechnology by Age



APPENDIX H: Comparing Nanotechnology Scientists' Patenting Involvement by Gender and Discipline

	Nano-Female		Nano-Male	
	N	Patent Invovlement (%)	N	Patent Invovlement (%)
Biology	2	0	3	100
Chemistry	19	31.6	16	48.5
CS	2	50	2	40
EE	21	28.6	17	70.8
Physics	31	22.6	9	33.3
Total	75	26.7	47	51.1

Note: CS – computer sciences, EE – Electronic Engineering

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